

XX.—ON THE DEVELOPMENT OF OSSEOUS FISHES, INCLUDING MARINE AND FRESHWATER FORMS.

BY JOHN A. RYDER.

I.—GADUS MORRHUA L. (*The Cod.*)

The main features of the development of this species have been described and illustrated in a previous memoir¹ by the author, so that it will not be necessary to do more than to add observations made since the publication of that paper, and otherwise complete the record of the early life-history of this important food-fish.

The views of Hoffmann² as to the meaning and sequence of the phenomena attending the fertilization of fish ova have been disputed since the above-cited essay was written, and apparently upon the basis of well-determined data. The most recent contribution to this subject is by Agassiz and Whitman,³ who state, page 19, in reference to the development of *Otenolabrus*, that "immediately after the penetration of the spermatozoon a disk-like thickening of the cortical layer appears at the lower pole of the egg; and at the center of this disk may be seen, in mounted preparations, the minute male pronucleus. It is a curious fact, of which the proof will be given in our second memoir, that the male pronucleus becomes the center of attraction around which the discoidal aggregation of protoplasm takes place, and towards which, after the formation of the second polar globule, the female pronucleus gravitates."

In another paper⁴ Agassiz and Whitman have also discussed the origin of the *periblast*, as it is called by them, reaching the conclusion that the "autoplasts" (Lankester), the free nuclei of authors, do not arise spontaneously in the layer of protoplasm underlying the germinal disk, nor from a single nucleus developed at the time of the first cleav-

¹ A contribution to the embryography of osseous fishes, with special reference to the development of the cod (*Gadus morrhua*). Report of the United States Commissioner of Fish and Fisheries, part x, for 1882, pp. 455-605, pls. xii. Washington, 1884.

² C. K. Hoffmann. Zur Ontogenie der Knochenfische, chapters i-viii, 4to. Amsterdam, 1881.

³ A. Agassiz and C. O. Whitman. The development of osseous fishes. I. The pelagic stages of young fishes. Studies from the Newport laboratory. Mem. Mus. Comp. Zool., xiv, No. 1, part 1, 4to, pp. 56, 19 plates. Cambridge, 1885.

⁴ On the development of some pelagic fish eggs, preliminary notice. Proc. Am. Acad. Arts and Sciences, xx, 8vo, pp. 23-75, 1 pl. 1884.

age, as held by Hoffmann (*op. cit.*), but are segmented off from the marginal cells of the segmenting blastodisk as suggested by the writer in his first paper on the cod.

With the further growth in diameter of the blastodisk the marginal cells, which are without well-defined outlines, are finally covered over by the spreading blastodisk. In this way the nuclei of the periblast (a layer which is in reality a syncytium) are finally brought into such a position that they seem to underlie the blastodisk. The nuclei in the periblast are, however, always most abundant near the edge of the blastodisk at an early stage of development. During the later stages the nuclei of the periblast are most numerous just beneath the embryonic axis, especially under the head.

The marginal segmentation, which gives rise to the so-called "free nuclei" of the periblast, first clearly described by Agassiz and Whitman, leads to the formation of a wreath of flat cells which form a more or less well-marked zone around the blastoderm upon the completion of the segmentation of the blastodisk. This marginal wreath of cells, "nuclear zone" of Kupffer, has been figured by the latter,⁵ E. Van Beneden,⁶ the writer,⁷ Brook,⁸ Cunningham,⁹ and by Agassiz and Whitman. The essential agreement of so many observers working upon very different species shows that this nuclear zone must be very generally developed in the eggs of Teleosts, and even amongst the Salmonidæ, where it is not so easily observed in the living egg, but which is shown in the sections figured by E. Ziegler.¹⁰

The development of this "nuclear zone" in the eggs of the cod escaped my observation when I studied the development of that species in 1881, but I have during the past year (1885) observed it, and have, moreover, satisfied myself that it arises as observed in *Ctenolabrus*, by Agassiz and Whitman, and that it is subsequently covered over by the spreading blastoderm, while the nuclei of the periblast, also subdivide by the indirect method, and proliferate inwards beneath the blastodisk. Cunningham's observations are in accord with these.

The synonymy of the term periblast may profitably be considered here. It obviously corresponds to the "white yolk" of the bird's egg;

⁵ Kupffer. Beobacht. ü. der Entw. der Knochenfische. Arch. f. mikr. Anat., iv, pl. xvi, fig. 1. 1868.

⁶ E. Van Beneden. A contribution to the embryonic development of the Teleosteans. Quar. Jour. Mic. Sci., xviii, 1 pl. 1878.

⁷ J. A. Ryder. Development of the Spanish mackerel. Bull. U. S. Fish Com., i, 1881, pp. 135-172, pl. i, fig. 4.

⁸ J. A. Ryder. Development of the silver gar. Bull. U. S. Fish Com., i, 1881, pp. 283-301, pl. xix, fig. 3.

⁹ Brook. Preliminary account of the development of the Lesser Weever-fish, *Trachinus vipera*. Journ. Linn. Soc. Zool., xviii, 1884, pp. 274-291, pl. iii, figs. 8, 9-9a.

¹⁰ J. T. Cunningham. On the relations of the yolk to the gastrula in Teleosteans, and in other vertebrate types. Quar. Jour. Mic. Sci., 1885, pp. 38, pls. iv.

¹¹ Die embryonale Entwicklung von *Salmo salar*. Inaug. Diss., Freiburg i, B., 1882. Taf. i, figs. 6-10.

"*Subgerminale Platte*" of Kupffer; *Dotterhaut* and *membrana vitellina* of Cellacher; *couche intermédiaire* of Van Bambeke; intermediary layer of authors; *parablast* of His, Waldeyer, Hoffmann, Gasser, Kupffer; *yelk-hypoblast* of the writer; *couche hæmatogène* of Vogt; and the *plasmédium* of Rauber.

The annular thickening of the periblast, just under the edge of the blastodisk, is clearly homologous with the *Keimwall* of His or the *Keimwulst* of Kölliker, as seen in the ova of Sauropsida. The function of this periblast is also clearly established throughout the various series of Vertebrates which develop meroblastic ova; its cells, in fact, incorporate yelk particles, by a process which is essentially one approximating that of intracellular digestion. Finally, the periblast may give rise directly to free cells, which pass into the vascular channels of the embryo as blood-corpuscles.

This disposition to absorb the underlying quiescent plasma is also shown by the lower cells of the true hypoblast which immediately overlies the periblast. Such hypoblastic cells which are larger than their neighbors have been called *megaspæra* by His, and have also been figured by Kölliker in the Avian blastodisk, while they have been encountered by the writer in the blastodisks of Teleosts.

In the eggs of the cod, as in most pelagic fish ova, the periblast is quite thin after the closure of the blastopore, but as the yelk diminishes in quantity with the progress of development this layer becomes decidedly thicker. The entire yelk is, in fact, first converted into the plasmodial substance of the periblast before it is absorbed by other parts of the embryo. It therefore results that the last portion of the yelk to disappear is the periblast.

The periblast is undoubtedly hypoblastic in position, and in many large-yelked forms is homologous with the splanchnopleure, as in the case of the embryos of Salmonoids, in which, together with the vascular network traversing it superficially, it eventually occupies the position of the splanchnopleural mesoblast in relation to the other layers.

(1) *Development of the hypoblast or the gastrulation of the egg.*—This almost threadbare subject I return to reluctantly, because so much which is erroneous has been written about it. Balfour's account in his *Comparative Embryology*, ii, 57, is far from clear, and conveys but little definite information as to the origin of the hypoblast. That the latter is developed as a "centripetal ingrowth of cells from the margin of the blastodisk" (Agassiz and Whitman) there can no longer be any doubt, though in my earlier studies on the development of the cod I opposed that view, because I had not succeeded in witnessing the process, which I have observed since in detail, as has also been done by Cunningham.

I find that the cells at the edge of the blastodisk are inflected around its entire margin, but that at the point where the future embryo is formed the ingrowth is most rapid, and soon becomes somewhat wider.

Later, the hypoblastic layer, which has arisen by the process of inflection just described, forms a sort of rounded promontory or tongue of cells, several deep, which is prolonged inwards under the epiblast with the progress of the development and the growth in length of the two-layered rudiment of the embryo. The views of Gœtte,¹¹ Haeckel,¹² Henneguy,¹³ Ziegler, Kingsley and Conn,¹⁴ Agassiz and Whitman, Brook, and of Cunningham, on this point, agree pretty closely as to the main fact of the occurrence of a marginal inflection of the blastodisk.

As observed by a number of investigators, the centripetal inflection of the margin of the blastodisk of Teleosts does not lead to the formation of a continuous plate of cells underlying the sensory layer of the epiblast, and of the same area as the latter. A very considerable area beneath the epiblast, and occupying an excentric position in the blastodisk, is not invaded by the ingrowing hypoblastic layer. The space not so invaded and bounded by the epiblastic layer above, the inflected lips of the hypoblastic layer at the sides, and by the periblast below, is the depressed or flattened blastocœl of the Teleostean ovum. It is perfectly homologous with that of *Branchiostoma*, but is flattened or depressed by the way in which the growth of the blastula is modified by the presence of a large yelk, which is itself invested by the periblast or yelk-hypoblast. The blastula becomes, in fact, a hollow disk.

The yelk-periblast or yelk-hypoblast, and the inflected hypoblast are hypoblastic in their relations, and must accordingly be invested in the course of development by the epiblast by epibole. The epiblast and hypoblast are accordingly fused at the margin of the blastodisk. The entire margin of the blastodisk must consequently be regarded as the blastopore or archistome of the developing Teleostean ovum, as originally implied by Haeckel. Such a condition of things would be brought about by loading or surcharging the cells of the hypoblastic pole of the blastula of *Branchiostoma* with yelk substance. The way in which the discoblastula arose may be very easily understood, if the gastrula stages of *Branchiostoma*, *Rana*, and *Gadus* are carefully compared.

With the gradual increase in the size of the yelk in the vertebrate series, it finally happens that the principal morphological features of the embryo are distinctly developed long before yelk absorption is completed. As a result of this, the yelk, which occupies a ventral position in reference to the intestine, is finally excluded from direct connection with the latter, and the periblast (hypoblastic in origin) is made to assume a new function, viz, that of ministering to the incorporation of

¹¹ Gœtte. Berlin. medicin. Centralblatt, 1869, No. 26, pp. 404-466, and Arch. für mik. Anat., ix, 1873, p. 679.

¹² Haeckel. Die Gastrula und die Eifurchung. Jena. Zeitschr., ix, 1875.

¹³ Henneguy. Note sur quelques faits relatifs aux premiers phénomènes du développement des poissons osseux. Bull. Soc. Philom. de Paris, 10 Apr., 1880, p. 4.

¹⁴ Kingsley and Conn. Some observations on the embryology of Teleosts. Mem. Bost. Soc. Nat. Hist., iii, pp. 183-212, pls. xiv-xvi, 1883.

the vitelline matter. Kollmann¹⁶ has lately presented some strong evidence in favor of this view, but is in error in assuming that the lips of the inflected rim (hypoblastic stratum) of the blastoderm are the lips of the blastopore. If this view is admitted, we are logically forced to conclude that the yelk is something extraneous, and is not an integral part of the ovum, as we know it to be, judging from the way in which the periblast arises. The manner in which the latter is formed shows that the continuity of the blastodisk with the plasmic layer investing the yelk is perfect, and that the cleavage cavity is exactly homologous with that developed in a holoblastic ovum. There is, therefore, a blastula stage developed in Teleosts which is most distinctly evident at the time the "nuclear zone" is formed. The vesicular syncytium formed by the periblast is, however, so enormously distended with passive yelk that gastrulation is modified to an extreme degree. Kollmann's arguments against the final closure of the blastopore at the edge of the blastoderm and at the hinder extremity of the axis of the embryo breaks down completely, if the processes of gastrulation of *Branchiostoma*, *Rana*, and *Gadus* are compared, because such a comparison shows: First, that a gradual loading of the entoblastic pole of the blastula with yelk causes the latter to be constricted around its equator in the course of development, thus leading to the formation of a blastodisk with an inflected two-layered margin. Secondly, since the foregoing is true, it results that active development is shifted so entirely towards one pole of the egg that gastrulation also occurs there, and an attempt is made to reproduce the state of things seen in the gastrula of *Branchiostoma*, but in the effort of the active pole of the blastula to envelop the passive one by epibole it appears as if the annular entoblastic invagination was incomplete, leaving the "Urmund" of Kollmann open. This "Urmund" is homologous with a circular opening which might be produced by a rupture near the center of the inflected entoblast of the gastrula of *Branchiostoma*, and therefore is in no sense homologous with the true blastopore. The opening in the floor of the discoblastula of Teleosts and Elasmobranchs, identified by Kollmann with the blastopore, I propose to call the *discopore*, in order to permanently distinguish it from the true blastopore of authors. An equally fatal objection to Kollmann's view is that on the basis of his interpretations the blastopore of Teleosts and Selachians would not open to the exterior.

A view resembling in some respects that of Kollmann was entertained by me in 1881 (see 7a, *supra*, p. 298), though it was immediately qualified in paragraph 2 which followed on the same page, and was subsequently adopted in a modified form in my first paper on *Gadus* (Contr. Embryog. Oss. Fishes, p. 569). I had also observed^{16a} and figured the segmentation of the "nuclear zone" or "marginal wreath of

¹⁶ Kollmann. Gemeinsame Entwicklungsbahnen der Wirbelthiere. Arch. f. Anat. u. Physiol., 1885. Anat. Abth. pp. 279-306, pl. xii.

^{16a} See No. 7, p. 146, fig. 4, pl. 1; and also No. 7a, p. 287, fig. 3, pl. xix.

cells" from the edge of the blastodisk. And contrary to what some of the more recent writers on Teleostean development would seem to imply, I had already suggested that the nuclear zone gave rise to the nuclei of the periblast, as the following quotation will show: "The free nuclei of the yelk-hypoblast apparently proliferate as the blastoderm spreads. They are, at any rate, at first confined to the germinal pole of the ovum, and are only found at the opposite pole after the yelk-globe has been included by the blastoderm. The inference, therefore, is that they spread and multiply with the lateral growth of the blastoderm. It is these nuclei possibly which are the centers of certain free cells around the margin of the germinal disk when the latter has attained the morula stage, as in *Cybium* and *Tylosurus*, as shown in fig. 3, pl. xix, of my essay on the latter form. If such is the case, it is possible that the germinal wall (*Keimwall*) at the edge of the blastoderm of the chick is homologous with the yelk-hypoblast of the fish ovum" (Contr. Embryog. Oss. Fishes, p. 569).

The marginal inflection of the blastodisk is figured by Kingsley and Conn (No. 14) in *Ctenolabrus*, and by Brook,¹⁶ ¹⁷ as being composed of larger cells than that of the epiblast. Kingsley and Conn represent only a single layer in *Ctenolabrus*, a condition which I have never found to exist in sections of the disks of any of the species studied by me. Brook represents several layers of larger cells in the hypoblast. That the inferior stratum of cells of the inflected hypoblastic layer are perhaps somewhat larger than those of the epiblast I admit, but that they are generally very much larger or that the inflected hypoblast is ever formed of a single layer, as held by Kingsley and Conn, I am disposed to question.

Cunningham (On the relation of the yelk to the gastrula in Teleosteans, etc.) has studied the development of three Gadoid forms, and has been the first English investigator who has declared himself an advocate of the concrescence theory, which, in its various forms, has been supported by His,¹⁸ Rauber,¹⁹ Whitman,²⁰ and myself,²¹ and latterly by Duval²² and Kollmann.

¹⁶ Brook. On some points in the development of *Motella mustela* L. Journ. Linn. Soc. Zool., xviii, Nov., 1884, pp. 298-307, pls. viii-x.

¹⁷ Brook. On the origin of the hypoblast in pelagic Teleostean ova. Quar. Journ. Mic. Sci., Jan., 1885, pl. iii.

¹⁸ W. His. Ueber die Bildung der Haifischembryonen. Zeitschr. f. Anat. u. Entwickelungesch., ii, 1877, pls. vii; also, Untersuch. üb. die Entwick. von Knochenfische, etc., in vol. i of same journal, 1 pl.

¹⁹ Rauber. Primitivstreifen und Neurula; also, Die Theorien der excessiven Monstra, Virchow's Archiv. lxxi, 1877, pls. 3.

²⁰ Whitman. Embryology of Clepsine. Quar. Jour. Mic. Sci., July, 1878, pp. 101, pls. xii-xv.

²¹ Ryder. On the formation of the embryonic axis of the Teleostean embryo by the concrescence of the rim of the blastoderm. Am. Naturalist, 1885, pp. 614-615, 1 fig.

²² Mathias Duval. De la formation du blastoderme dans l'œuf d'oiseau. Ann. Sci. Naturelles. Zool., 6^e sér., tome xviii, pp. 208, pls. 5, 1884.

The strenuous opposition to the doctrine of concrescence manifested by Balfour arose apparently from his too constantly interpreting all of the higher vertebrate types of development upon the basis of his brilliant researches on the Elasmobranchs. Later research has only confirmed the doctrine and added little except a clearer knowledge of the details of the process, and I may add that Whitman has recently gone over the subject of the concrescence of the germ bands in *Clepsine*, and will shortly present the most conclusive evidence of the soundness of the views which he originally published in 1878. The evidence as to its occurrence in *Gadus* becomes palpable upon the advent of the initial steps of the inflection of the blastodermic margin. The inflected layer soon becomes wider in the region where the embryo is formed and is prolonged with the progress of the extension of the blastoderm over the yolk. The concrescence of the lips of the primitive blastopore in the middle line of the embryo would also tend to carry a larger number of periblastic nuclei under the anterior and middle region of the true hypoblast. It does not necessarily follow, however, that the floor of the intestine is formed by cells derived from the periblast, as occurs in Elasmobranchs (*teste* Balfour), and as held by Cunningham, though there is no objection to such a view. The principal conclusions reached by Cunningham as to the homologies of the yolk-blastopore are, however, not new, as Rauber²³ and myself²⁴ had previously reached the same or very similar interpretations.

Rauber considers what I have called the "yolk-blastopore" to represent the "*blastostomion verum*" or true blastopore in types with a large yolk. The blastopore of the latter types, usually regarded as such by embryologists, and developed at the anterior part of the primitive streak, Rauber calls the "*blastostomion consecutivum seu intermedium*." Both openings together are for him simply differentiations of the primitive "blastostome." This blastostome, or the blastopore, as it is usually called, of the Bilateralia, whether round or drawn out into a cleft by a process of growth in length, or of concrescence, I have elsewhere²⁵ distinguished as the *archistome*.

(2) *Later development*.—The more advanced stages of the cod embryo, though studied by Sars and others, have never been correctly figured by any one because of the fact that a very large vesicle on the upper side of the head has been entirely overlooked, probably because of the extreme transparency of this portion of the young fish. In my first paper on the development of the cod (*Contrib. Embryog. Oss. Fishes*, pls. xi and xii), figs. 45 and 49, which are side views of embryos, figured ten and seven days after hatching, give the erroneous impression that the median fin-fold extends quite forward between the nasal

²³ Rauber. Die Lage der Keimpforte. *Zoolog. Anzeiger*, ii, 1879, pp. 499-503.

²⁴ Ryder. On the position of the yolk-blastopore as determined by the size of the vitellus. *Am. Naturalist*, April, 1885, pp. 411-415.

²⁵ Ryder. The *Archistome* Theory. *Am. Naturalist*, Nov., 1885, pp. 1115-1121.

pits. The same would also be inferred from another figure representing an advanced larval cod, published in a later paper²⁶ by the writer.

The true state of the case is as follows, as may be gathered from figs. 1 and 2, plate i: The true median dorsal fin-fold only extends as such forwards as far as to about or slightly behind a vertical line passing through the base of the pectoral. The larval integument continuous with the median dorsal fin-fold and covering the brain and fore part of the spinal cord is not prolonged forwards as a flat duplicature or fold, but is distended as an oblong vesicle and filled with a serous fluid, as shown from the side in fig. 1 and from the front in fig. 2.

Immediately after hatching, this sinus or space between the integument and the brain is small, as may be observed in fig. 40, plate ix, of my first paper, but in about one day after hatching it begins to be obvious that the integument, over the brain and as far back as to the vertical from the end of the intestine, is being lifted up and becoming filled with fluid. This proceeds until at the end of a week or ten days the larval cod, when viewed from the side or front, presents a most singular resemblance to the conventional dolphins of the ancient sculptors. The rounded and swollen front and top of the head is in marked contrast with the majority of pelagic fish larvæ.

That the integument is actually lifted up from the underlying structures is shown by the fact that the long efferent branches of the vagus group of nerves which pass outward to button-like thickenings of the epiblast armed externally with stiff protoplasmic hair-like processes, may be traced through the wide space between the integument and the brain when the embryo is examined by transmitted light. Three pairs of such segmental sense organs or neuromasts (Wright) are found in the walls of the large integumentary vesicle overlying the head and body of the young cod. These organs are disposed quite symmetrically on the fore part of the body, but posteriorly they are not symmetrically disposed on the sides of the tail, as may be seen by referring to plate x, fig. 42, Embryog., Oss. Fishes. Agassiz and Whitman, in their last memoir (Pelagic stages of young fishes), also figure and describe larval fishes in which there was more or less asymmetry noticeable in the arrangement of the caudal neuromasts.

The great anterior dorsal integumentary vesicle of the larval cod is gradually developed after hatching, and appears to increase in size as the yolk sack diminishes and becomes empty. I first noticed and described what is obviously homologous with this vesicle, which is so exaggerated in dimensions in the larval cod, in 1881, in the Spanish mackerel, as may be learned if the reader will consult plates iii and iv, figs. 14, 15, 16, and 17, illustrating my paper on the development of that species (Bull. U. S. Fish Com., i, 1881, p. 157), where it is also stated that it is developed after hatching, as is shown by the con-

²⁶ Ryder. An outline of a theory of the development of the unpaired fins of fishes. *Am. Naturalist*, Jan., 1885, pp. 90-97, fig. 3.

dition of the vesicle in a larva just hatched and figured on plate ii of the paper cited. At that time I named the space in the supracephalic vesicle of the Spanish mackerel, the "supracephalic sinus." Now, while it is clear that this sinus is the homologue of the much larger one in the larvæ of *Gadus*, it is also clear that in the latter it extends not alone over the brain as in *Scomberomorus*, but even back dorsally beyond the hinder limits of the body cavity.

I have good reasons for believing that a sinus of the same character overlies the brain in a number of the species figured by A. Agassiz and his associate Whitman as well as in the larvæ of *Trachinus* and *Motella* figured by Brook. In fact, I doubt if the structure represented in advance of the first developed dorsal fin-ray on the head of the larva of *Lophius* by A. Agassiz²⁷ is a fin-fold at all, but merely the integumentary vesicle or bulla described above, though the contrary is expressly stated on page 282 of the memoir last cited. A still more remarkable instance of the extension apparently backward and laterally of what I have called the "supracephalic sinus" is represented however by Agassiz and Whitman on plate xii, figs. 7 and 8, of their recent memoir (Pelagic stages of young fishes, part I, 4to, 1885). In this form the sinus has been extended back for two-thirds of the length of the larva and also over the sides of the head. The form in question is supposed by its describers to be near *Motella*.

It is therefore probable, taking into account the facts recited above, that the true, median, dorsal fin-fold is never extended as far forward as the front of the head, as I had assumed in my paper cited above on the development of the median fins, but that such an apparent anterior dorsal extension of the fin-fold is due to the illusion produced by the extreme transparency of the integument of the dorsal vesicle or bulla just described, the presence of which is not easily made out until the living embryo is viewed from in front. The true median fin-fold in the larvæ of *Gadus* is therefore but little longer proportionally than that of other types of larvæ which are without a supracephalic bulla. The archaic extension of the fin-folds in fishes therefore, it seems, must have been about the same as that generally prevalent to-day in young larvæ, or an extension of the fin-folds which is most nearly approximated by such adult forms as the *Dipnoi*.

The contents of the bulla or sinus have been but little studied, but it is probable, judging from certain observations upon the contents of the fin-folds of larval fishes by Emery,²⁸ that this bulla in *Gadus* contains coagulable albumen. I have found such a coagulum in the fin-folds of hardened embryos of *Clupea*. And in embryos of *Scomberomorus* I found loose granular matter in the sinus on the top of the head and fin-folds.

²⁷ A. Agassiz. On the young stages of osseous fishes. Part iii, Proc. Am. Acad. Arts and Sci., xvii, 1852, pls. xvi, xvii.

²⁸ Emery. Sulla esistenza del cosiddetto tessuto di secrezione nei vertebrati. Atti R. Acad. Sci., Torino, xviii, 1883.

In larvæ of *Gadus* hardened in chromic acid there seems to be such a coagulum existing in the dorsal bulla already fully described. This bulla therefore partakes of the nature of a lymph-space.

(3) *Changes of position of the cod's egg and embryo during development.*—

The germinal disk of the cod's egg, like that of the ova of most Teleosteans, is developed at the time of impregnation. The single spermatozoön necessary to effect impregnation and initiate developement enters the egg through a minute round pore in the egg-membrane or zona radiata, known as the micropyle. But one such opening is found in the egg of the cod, and I believe that reliable authorities concur in the belief that there is but one such opening in the membrane which invests the ovum of Teleosts.

The male element can therefore enter the ovum at one point only, and, inasmuch as the superficial cortical layer at the time of impregnation, and from which the blastodisk or germ is developed, lies in immediate contact with the egg-membrane or zona, the point of contact between the egg and spermatozoön is also limited by the area on the ovum covered by the micropyle. That area is excessively small. The polar cells in the cod's egg are also extruded immediately beneath the micropyle and invariably in very close relation to it. Furthermore, the active plasma of the egg gravitates towards the point where the spermatozoön entered the egg, and the greater part thus accumulates in the vicinity of the micropyle, as shown in fig. 3, pl. i, where the polar cells joining the egg to its membrane are also indicated. I never saw any polar globules expelled through the micropyle.

As soon as the blastodisk becomes apparent as a thickening or aggregation of the substance of the cortical layer it assumes an inferior position, because the specific gravity of the plasma of the disk is greater than the same volume of yelk, the whole of which now occupies the upper pole of the egg. Later still, when the disk *D*, fig. 4, is better defined, the force of gravity, still acting in the direction of the arrow, which points toward the micropyle, constantly keeps the disk in an inferior position, which is maintained until the blastodisk begins to spread and the embryo to be formed. When the blastodisk or the blastoderm, as it may now be more appropriately called, has spread over one-half of the vitelline globe, as shown in fig. 5, the embryo is pretty well defined at one side of the blastoderm, and extends from its margin to its center. This causes the blastoderm to become heavier at the side upon which the embryo is formed, and, as a consequence, the whole egg is slightly rotated upon its own center so that a radius drawn from the latter to the center of the original site of the blastodisk of an earlier stage will be inclined to the horizon at an angle of 45°. As development proceeds still further the embryo of course lengthens as the blastoderm spreads, till finally the embryo embraces an arc of 180° on the yelk-globe. As a result of this the radius passing from the center of the egg to the original site of the center of the blastodisk

is swung round still farther, so that the total rotation of the egg now amounts to about 90° , as a comparison of fig. 6 with fig. 4 will show, as indicated by the arrows.

Further changes of the position of embryo in the egg as development advances are hard to follow, but these are the principal and most striking ones. When hatching takes place the vitellus is always so much lighter than the embryo that the latter floats about in the water on its back. In the course of a day or so the embryo is able to right itself.

The next change in the position of the free embryo, when at rest in the water, occurs some days after hatching and seems to result from the development of the great bulla already described and which is gradually developed on the head and over the upper part of the body. When larvæ of a few days old swim they are inclined to move the body forward horizontally in a right line, but as soon as they come to rest the tail drops down into an inclined position, and forms an angle of about 45° with the horizon. This was so constantly observed to be true of advanced embryos that I have inferred that the bulla developed on the head caused the latter to be buoyed up, just as the less advanced embryo is buoyed by the yelk before its absorption. This seemed all the more probable from the fact that the very rudimentary air-bladder in larvæ of that age does not as yet appear to contain air.

The function of the integumentary bulla on the head, therefore, seems to be, in part at least, to serve as an organ aiding in the flotation of the embryo. This seems all the more probable from the strongly marked pelagic tendencies manifested by the eggs and larvæ of the cod at all stages in sea-water of normal specific gravity or in water having a density of 1.025.

(4) *The most recent and successful method of hatching cod and other pelagic eggs.*—I will here reproduce in part what I have already published elsewhere.²⁹

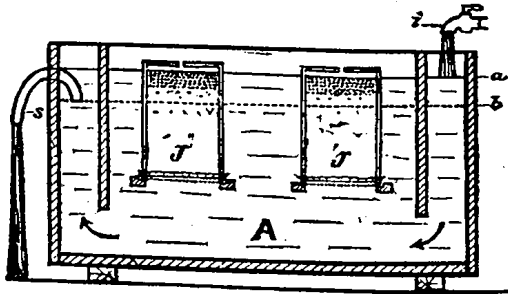
For four seasons experiments have been carried on for the purpose of discovering a practical method of hatching the eggs of the cod—one of the most fertile and valuable of the food-fishes found off our coast. During the period mentioned no less than forty forms of apparatus have been devised and operated, with varying success, by different persons connected with the work of the U. S. Fish Commission. Up to the present time no device has fulfilled the required conditions, even approximately, with such success as the apparatus just devised by H. C. Chester, superintendent of the Wood's Holl station of the Commission.

This apparatus is essentially automatic, and needs so little attention that one man will by its aid readily care for a hundred millions of eggs. It consists of a trough, 7 feet 6 inches in length, 2 feet in width, and 2 feet 4 inches in depth. At about 1 foot from either end, vertical wooden partitions, extending to within 4 inches of the bottom of the trough,

²⁹ Ryder. Success in hatching the eggs of the cod. *Science*, vii, 1886, No. 153, pp. 26-28. Also, Hatching codfish eggs. *Forest and Stream*, xxv, No. 25, Jan. 14, 1886, p. 488.

are secured. This leaves a space about 5 feet 6 inches in length between the partitions. In this space 6 or 8 large glass jars are supported upon a frame, with their tops downward. Those used for the purpose at Wood's Holl are ordinary cylindrical, four-gallon specimen jars, with a half-inch hole drilled in the bottom. The stoppers of the jars are removed, and a single thickness of coarse cheese-cloth is secured over the mouth with strong twine. The jar is then inverted and lowered into trough, so that its bottom is about even with the top of the trough. Strips nailed across the top of the trough serve to keep the jars upright.

The accompanying figure, showing the device in longitudinal vertical



section, modified and designed on a somewhat smaller scale than the device now in use and accommodating only four jars (two in a row), will enable the reader to get a clear conception of the way in which the apparatus is used. The trough *A* is filled with unfiltered sea-water through the faucet *i*, the water rising to the level of the line *a* before the capacious outlet siphon *s* begins to operate. This siphon, through which the water runs out of the trough faster than it comes in at *i*, soon brings the water down to the level of the line *b*, when the siphon takes in air and ceases to operate, after which the trough again slowly fills up with water to the level of the line *a*. This process is repeated automatically, and as long as the water is permitted to flow through the device. It requires ten minutes for the water to rise or fall from the one level to the other; and, since the jars have only a cloth tied over the mouth below, the water rises and falls to the same extent in them. This very slow and gentle rise and fall of the water in the jars and trough has been found sufficient to aerate the eggs and give them all the movement they need.

All of the good eggs in this contrivance float at the surface; some, during the latter stages of hatching, will fall below the surface, but if such ova are washed, they will again rise to the surface, and an exceedingly small percentage of the eggs ever sink and die, as in almost all of the other forms of apparatus hitherto used. The result is that the mortality is probably under 5 per cent—a percentage of loss not greater than that experienced in the most successful treatment of shad ova in the McDonald jar.

The freshly fertilized ova, treated with an abundance of good milt, are introduced into the hatching device through the hole in the center

of the bottom of each jar by means of a glass funnel. Beyond an occasional siphoning-off of the sediment on the bottom of the trough and the cloth covers of the jars, the eggs require no attention until hatched.

Heretofore great mortality has been caused by the use of metal in the construction of hatching vessels and strainers. Since the adoption of glass, wood, and cloth as the only materials used in the construction of the hatching apparatus here described, combined with the very gentle movement to which the eggs are subjected, complete success has been attained. The eggs are caused to oscillate up and down through a space of only 5 inches from the level of *a* to that of *b*, and, withal, so gently that they suffer no hurtful shocks of any kind whatever. Captain Chester's device will doubtless be used with great advantage in the propagation of the Spanish mackerel. In twenty-four hours the embryos of the latter would be ready to be set free from the apparatus; whereas it requires eleven or twelve days to hatch the eggs of the cod, with the temperature of the water ranging from 45° to 48° Fahr.

Each of the jars *J* is 17 inches high by 9 inches in diameter, and will hold from one-half to one million of cod eggs; so that an apparatus of the style shown above, and occupying not much over a square yard of space, would accommodate from two to four millions of ova, in four jars.

These results and experiments show that violent movement of the eggs of the cod is of no advantage; that such movement is, on the contrary, injurious if not mortal when continuously maintained. The requisite conditions for the successful hatching of this important food-fish having been settled, the great station of the Fish Commission at Wood's Holl affords unlimited opportunities for conducting the work for at least three months of the year, during which time from five hundred to one thousand millions of eggs might readily be hatched out by the aid of the Chester apparatus and set free in the adjacent waters.

The proper specific gravity of the sea-water has a great deal to do with the healthy development of the eggs of the cod. By accident a broken valve admitted fresh water to the pumps which supplied our salt-water tanks, causing the specific gravity of the water to fall from 1.0256 to 1.021 or 1.022. In the latter densities the eggs immediately sank, but rose at once if placed in sea-water of the specific gravity first mentioned. The break in the valve through which fresh water was added to that which was pumped from the harbor for use in our hatching troughs, caused us to lose over two millions of good eggs. After this unfortunate experience, and also judging from the fact that ever since the break in the valve has been mended no eggs have sunk or subsided to the bottom, we have concluded that the cod egg, in order that it may develop normally, must float at or near the surface. Under no other conditions does it seem possible to get them to develop regularly and without serious losses.

It was also found in the course of subsequent experience that the constant flow of cold water around the jars immersed in the troughs

tended to keep the temperature in the latter constant, so that all the eggs developed at the same rate. In other apparatus devised in imitation of Chester's device, but in which the hatching vessel was not surrounded by a constant supply of fresh, cold sea-water, irregularities of development were often very pronounced. This seemed to be due to the unequal temperature of the water at the sides and center of the vessel, owing to radiation from the atmosphere of the room. In these other forms of apparatus, development seemed to proceed normally until within a day or two of hatching, when the eggs would suddenly sink and die.

(5) *The post-larval stages of development of the cod.*—I have not seen any of the more advanced stages; none older in fact than about ten days after hatching. A. Agassiz³⁰ has figured two stages believed to appertain to the common cod. These show the chin barbel and the ventral fins developed, neither of which were yet developed in the oldest stages seen by me. These specimens measured respectively 20 and 28^{mm} in length, or from four to five times as long as the oldest specimens I have seen, so that there still remains a large gap to be filled up in the iconography of the stages of development of this species.

II.—*ROCCUS LINEATUS* (BLOCH) GILL. (*The Striped Bass, or Rockfish.*)

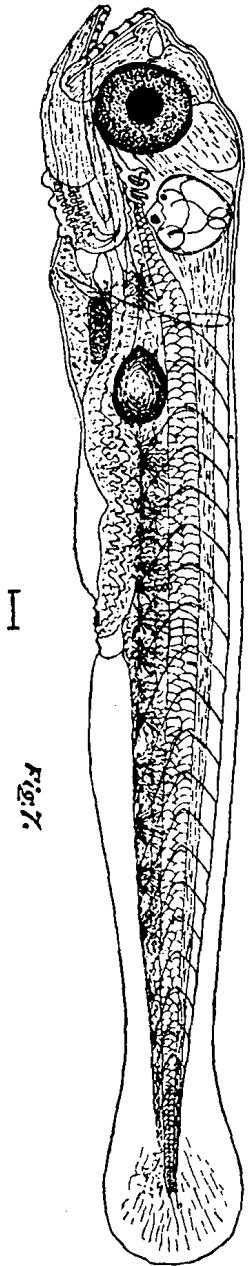
The artificial fertilization of the eggs of the striped bass was, I believe, first accomplished by Mr. E. H. Walke, of the United States Fish Commission, in 1879, and in 1881 Mr. S. G. Worth³¹ reported his success of the previous year in the artificial fertilization of the eggs of this species. The species is very fertile; a single female was estimated by Mr. Worth to have contained 3,000,000 eggs in her roes. Spawning and hatching appear to occur in fresh water, and according to Mr. Worth the eggs are of less specific gravity than those of the shad, extremely transparent or pellucid when in the water, and measuring nearly one-seventh of an inch in diameter after impregnation, when the zona radiata becomes greatly distended and freed from contact with the vitellus. The freshly extended ova were found to be smaller than those of the shad, and the vitellus was of a decidedly greenish color. From the foregoing data it may be assumed that there exists in the egg of this species, as in that of the shad, a very spacious "breathing chamber," or water space, developed between the vitellus and zona at the time of impregnation, in consequence of the distension of the latter with water taken in through the pore-canals. At a temperature of 66° to 67° Fahr. hatching began at the end of 48 hours.

The foregoing information is derived from the paper by Mr. Worth, and, as there can be no doubt of the fact that the eggs taken were those of the striped bass, we must suppose, if the young fish identified by A.

³⁰ A. Agassiz. On the young stages of osseous fishes, part iii. Proc. Am. Acad. Arts and Sci., xvii, 1882, pl. viii, figs. 4 and 5, p. 296.

³¹ S. G. Worth. The artificial propagation of the striped bass (*Roccus lineatus*) on Albemarle Sound. Bull. U. S. Fish. Com., i, 1881, pp. 174-177.

Agassiz really were of the same species, that the development of its ova occurs in fresh as well as in sea-water. The larvæ captured and figured by Agassiz,³² though it is nowhere specifically implied that these young fishes were not taken from fresh water, were probably captured in salt water, as were most of the forms figured by him. Specimens in my possession of young striped bass one day old, hatched from ova fertilized with the milt of the white perch, *Koccus americanus* (Gmel.) J. and G., measure 3.5^{mm} in length, or the same as the youngest stage figured by Agassiz, but the jaws and mouth are not nearly as well developed and the intestine is relatively much longer, nor are the median fin-folds as wide. The intestine also in this youngest stage extends backward beyond the yelk-sack for a distance equal to half the length of the latter before it reaches the edge of the ventral fin-fold to terminate at the anus. These differences lead me to think that the larval fishes figured by Mr. Agassiz as pertaining to the species here under consideration, must belong to another form, as none of his figures can be reconciled with those taken from larvæ of the striped bass, the parentage of which is undoubted. In this opinion I am most conclusively confirmed by a drawing which has fallen into my hands, by the late Prof. Henry J. Rice, the figure in question being drawn from a larval bass in May, 1879, on the sixteenth day after hatching, and which had been reared from a lot of eggs which were artificially impregnated. This drawing, which is reproduced here, fig. 7, was taken from a young fish measuring 5^{mm} in length, and disagrees in many important respects from a young fish of the same length and represented in fig. 3, plate i, in the paper by Agassiz already cited. The figure by Rice shows the tail of the young striped bass to be distinctly spatulate and rounded, and not tapering and rather acutely rounded, as figured by Agassiz. In Rice's figure the anus is situated at a point very nearly midway between the tip of the snout and the end of the tail; in the figure of the same stage given by Agassiz the vent opens at a point on the ventral border far in advance of a point situated midway between the end of the snout and that of the



³²A. Agassiz. On the young stages of osseous fishes. Part iii, Proc. Am. Acad. Arts and Sci., xvii, 1882, pp. 274-275, pl. i.

tail. Very pronounced hooked teeth are shown in both jaws in Rice's figure, and the air-bladder is developed relatively farther back than is shown in the figures given by Agassiz. The earlier stages which I have seen of undoubted embryos of *Roccus lineatus* are likewise more slender than those figured by Agassiz, and this point is also confirmed by the later stage figured by Rice.

HYBRIDIZATION OF THE STRIPED BASS WITH OTHER FISHES.

It is rather extraordinary that the striped bass should so readily lend itself to the purpose of cross-fertilization with other closely allied species, such as the white and yellow perch, but it is still more astonishing that it should be possible to cross this species with another belonging not simply to a different family, but even to a widely different order and sub-class. That the eggs of the shad (*Clupea sapidissima*) might be fertilized with the milt from the male striped bass seems almost incredible, yet it seems that the evidence showing that the eggs of a physostomous form may be fertilized by the milt from a physoclistous acanthopterygian is incontestable, and that the eggs of the latter type may even be fertilized with milt taken from the first-mentioned type. The shad and striped bass therefore appear to be fertile *inter se*, as the following evidence seems to prove.

That the shad ovum may be fertilized with the milt of the striped bass seems to be established by the evidence presented in a paper³³ by the writer published in 1883, from which I quote as follows:

A number of young fish which had already lost their yelk-sacks, in consequence of which it is to be supposed that they were already several days old, were received from Havre de Grace, Md., at the central station on the evening of June 13, 1882. They were immediately placed in an aquarium, but all of them died in a day or two after save about fifty, which were transferred by the writer to one of the smaller of the carp ponds in charge of Dr. Rudolph Hessel, where, as Professor Baird had suggested, they might possibly find some food suited to their wants and grow large enough for us to learn something of their future history. The case is an extraordinary one, as the possibility of interbreeding members of such very distinct families as the Clupeoids and Percoids, unless the impregnation was performed under the very eyes of the naturalist, might well be doubted by those familiar with the recorded facts which have generally been considered to prove that fertile interbreeding even between different genera was out of the question. The evidence in favor of the fact in this case is, however, too strong to be passed over, and until we know more of the later history of this singular hybrid, the following notes on the differences which were presented by the embryos in question when compared with those of the true shad

³³ Ryder. Notice of an extraordinary hybrid between the shad and striped bass. Bull. U. S. Fish Com., ii, 1882, p. 187.

must suffice. The striped bass was the male and the shad the female parent in this case.

Teeth more numerous and more recurved in the lower jaw; at least three pairs present; only two pairs in the larvæ of the shad of the same age. Lower jaw longer, with the gape of the mouth much wider; ear capsule proportionally much larger than in shad larvæ of same age, and pigment and fine radii of fins slightly more developed than in the latter. Intestine much more slender, that is, its lumen is much less spacious than in larvæ of *Clupea*. Liver in about the same position as in larval *Clupea*, but gall-bladder and eye relatively and perceptibly larger; Meckel's cartilage a fourth longer. General form that of the larval shad, but head more prolonged and acuminate anteriorly. The preponderance of characters appears to be those of the female parent, and these larvæ appear to be undoubted hybrids. The eggs were taken by some of the crew of the steamer Fish Hawk at Havre de Grace, and were impregnated with the milt of the striped bass, because no ripe male shad happened to be at hand.

The head of this singular hybrid, represented by fig. 11, plate ii, may be compared with fig. 7, representing an advanced larva of the striped bass, also with the figures of the larvæ of the shad, shown on plate xxii.

Since the foregoing appeared Mr. R. B. Roosevelt has published a paper³⁴ on hybridism between the striped bass and shad, in which the former was the female and the latter the male parent. No specimens of these larvæ appear to have been preserved so that all the information I can give in this instance is to quote Mr. Roosevelt's remarks on the subject as follows:

"A ripe female striped bass or rockfish, *Labrax lineatus*, being caught in the nets during the course of operation of the shad hatchery on the Hudson River, and there being no male bass to be obtained, the eggs were taken and brought into contact with the milt of the male shad, *Alosa sapidissima*. Then these eggs were placed in a box entirely by themselves, and every precaution was taken to make the experiment perfect. The eggs hatched; of that there is no question, but whether the product was the result of that impregnation or whether it was reached by the chance contact with floating seminal animalcules from bass, or whether the young lived after they were hatched, may be regarded as still open for consideration. As there was no possibility of keeping the fry in confinement the experiment goes no farther than opening the field of study and research."

III.—*CLUPEA VERNALIS* MITCH. (*The Alewife or Branch Herring; Gaspereau.*)

This Clupeoid is anadromous and lays its eggs in adherent masses; the zona is much thicker than that of the egg of *C. sapidissima*. The

³⁴R. B. Roosevelt. Fertility in hybridization. Proc. Am. Ass. Adv. Sci., xxxiii, 1885, pp. 510-515.

egg of this species is also very much smaller than that of the shad, and as the zona invests the vitellus or embryo quite closely, there is no spacious breathing chamber developed at the time of impregnation, as in the egg of the shad.

Fig. 8, plate ii, represents a larval *Clupea vernalis* on the second day after hatching, when it measures very nearly 5^{mm} in length. It is extremely transparent, the only ornamentation with pigment spots is a row of small ones on either side of the tail, on a level with the lower side of the intestine. The yelk is very clear and does not contain any oil drops. The liver is produced as a nearly solid, elongated outgrowth from the inferior side of the intestine and behind the yelk sack, in the same position as in *Clupea sapidissima*. The liver is represented in the figure by the long black patch behind the yelk sack. It will also be noticed that the intestine terminates very far back, as it does in fact in most Clupeoids.³⁵

IV.—IDUS MELANOTUS. (*The Golden Ide.*)

The ova of this beautiful cyprinoid are adhesive, and, like those of the gold-fish, are usually found to adhere singly to the water-plants amongst which the parent fishes spawn. The zona radiata is rather thick, and there is but little space between it and the vitellus.

The young golden ide when it leaves the egg measures 6.6^{mm} in length. Its form at that time is shown in fig. 9, plate ii. The Cuvierian ducts embrace the anterior end of the yelk, which is composed of small spherical refringent granules. The yelk sack is much prolonged, and extends from the cardiac region nearly to the vent, tapering slightly as it is prolonged backwards. As in cyprinoids generally, there is a complete circulation at the time of hatching, which is not the case with the embryos of several clupeoids and many forms having pelagic eggs. The figures given by Von Baer of the embryos of other forms of cyprinoids also show the yelk-sack to be elongated. (See his *Untersuchungen über die Entwicklungsgeschichte der Fische*, 4to, Leipzig, 1835.)

V.—CARASSIUS AURATUS. (*The Gold-fish.*)

The ova of the common gold-fish are laid singly upon weeds and other fixed objects in the water. They measure about 1.5^{mm} in diameter, and develop with comparative rapidity, hatching in 8 or 9 days after fertilization. Three of the earlier stages of the development of this form are shown in figs. 16, 17, and 18, plate iii. The yelk is quite granular and similar to that of *Idus* and *Leuciscus* (Van Bambeke³⁶), and the embryonic axis embraces almost the entire circumference of the vitellus,

³⁵ Filippo de Filippi. *Nouvelles recherches sur l'embryogenie des Poissons*, Ann. des Sci. Nat. 3^{me} Ser. Zool., vii, 1847, pp. 65-72, 1 plate. (Figures the larva of *Clupea finta*.)

³⁶ Van Bambeke. *Recherches sur l'embryologie des Poissons Osseux*. *Mém. Cour. de l'Acad. ray. de Belgique*, XL, 1875, Pl. II.

so that the blastopore closes beyond a point opposite the original site of the blastodisk, as also happens in *Leuciscus*. The vesicle of Kupffer is well developed just under the caudal end of the embryo, as may be seen by referring to figs. 16 and 18.

A more advanced embryo is represented in fig. 10, plate ii, measuring 5.75^{mm} in length, at five and a half days old. The ornamentation of pigment spots is quite elaborate at this stage. The yolk is elongated and fusiform, and its anterior end is embraced by the Cuvierian ducts. Just behind the urinary bladder the caudal vein is dilated and forms a fusiform sinus. It is then continued forward over the yolk, upon the dorsal surface of which it breaks up into a coarse vascular network.

For many weeks after hatching the young gold-fish does not develop any red or bluish-black pigment cells in the skin. When these are developed, which occurs after the fish is an inch or more in length, it is probable that the fish is approaching adolescence, as it has been found that this species reproduces when still comparatively small.

VI.—ELACATE CANADA (LINN.) GILL. (*The Crab-eater*.)

The ova of this species are very well characterized. They are pelagic, in salt water having a density of 1.020. A large and refringent oil globule is imbedded in the yolk at a point nearly opposite the site of the blastodisk and at the upper pole of the egg. The blastodisk is directed downward, like that of most pelagic fish ova. The egg measures about 1.25^{mm} in diameter and the yolk is broken up into a few very large irregular masses of deutoplasm, separated by thin films or processes of the cortical layer of protoplasm, as is indicated by the network of dotted lines in figs. 13 and 14, plate iii. This subdivision of the vitellus by thin sheets of plasma running into the yolk-substance is apparent even in the yolk-sack of the young fish after it is hatched.

The changes undergone by the developing blastodisk for the first four hours are quite complex. The development is quite rapid, and hatching takes place in about 36 hours after impregnation. A broad zone of marginal cells are segmented off from the margin of the blastodisk, and the margin of the latter is rapidly inflected. The growth of the blastoderm is quite rapid, the entire vitellus being included and covered over by the epibolic growth of the blastoderm in about eight hours.

As I have already referred to the very remarkable phenomena observed by me just previous to the closure of the blastoderm in this species, and not being likely soon again to have an opportunity to study the same form, I will now describe and figure what was then observed in a number of ova, from which I infer that the peculiarity about to be described is characteristic of the development of this form.

Fig. 13, plate iii, represents the embryo formed and lying on the surface of the vitellus, and is shown as if foreshortened; anteriorly the optic lobes *op*, on the other side of the vitellus, show through the trans-

parent surface of the latter. The embryonic axis shows the segments or somites *m*, distinctly developed, but it is very remarkable that the segmentation does not end at the point where the axis of the embryo, thus far developed, ends. The right and left limbs of the blastodermic rim, or lips of the blastopore, form a Λ -shaped mass, together with the embryonic body anteriorly; but, unlike any other normal Teleostean embryo, both the diverging limbs of the rim of the blastoderm show distinct indications of metamerie segmentation at *m*, and behind the point where conerescence has already taken place.

Just within the yolk and a little in front of the yolk blastopore, which runs forward into the acute angle formed by the limbs of the blastodermic rim *br*, lies the large oil-drop *o*. A lozenge shaped mass of cells lies in the acute angle of the Λ -shaped terminal part of the embryo, which appears to contain or overlie Kupffer's vesicle, *kv*, and what was assumed to be the posterior end of the chorda *ch* at the time the drawing was made; but of the certainty of this determination I am not at present satisfied. I was enabled to sketch this and a slightly more advanced stage several times, and, as already stated, I found the same condition of things present in a number of embryos, which appeared to be developing normally. Four other sketches show that the blastoderm finally closes very much as in other Teleostean embryos, and that pronounced wrinkles radiate from the crater like opening upon the yolk where the yolk-blastopore finally closes.

The conclusions of His and Rauber, to the effect that the embryonic axis is formed by the gradual fusion from before backwards of the edges or lips of the yolk blastopore as it advances over the surface of the vitelline globe, are completely and emphatically confirmed in the case of this species. It must be admitted, however, that the presence of the cellular mass between the limbs of the blastodermic rim where they join the anterior portion of the embryonic body is not a little puzzling.

This species I was enabled to study, through the kind help of Col. M. McDonald and Mr. W. P. Sauerhoff, at Cherrystone, Va., during the first week of August, 1881.

VII.—SIPHOSTOMA FUSCUM (STORER) J. & G. (*Common Pipe-fish.*)

The earliest noteworthy observations upon the development of any species allied to the one here considered, which I have been able to find, were recorded by Rathke.³⁷ The embryos of a species called *Syngnathus argentatus* is figured on plate v of Rathke's memoir, and he shows the gill clefts exposed or uncovered in the young, a condition not observed by later authors. The next memoir in historical order is by A. de Quatrefages, and deals with another species, probably another genus, in which the eggs are not covered by lateral folds extending down from

³⁷H. Rathke. Zur morphologie; Reisebemerkungen aus Taurien. 4to, pp. 192, pls. 5, Riga and Leipzig, 1837.

the sides of the body. The memoir of de Quatrefages³⁸ is, however, very superficial, for the courses and distribution of the blood-vessels in the embryo are drawn altogether diagrammatically and with the help of the imagination of the artist. The next paper³⁹ published was by the writer, in which some of the stages of development of *Siphostoma fuscum* were discussed and described. About two years later Dr. J. P. McMurrich took up the study of the development of this species and published a memoir⁴⁰ which is valuable for the information it affords as to the ontogeny of the cranial skeleton.

The eggs of *Siphostoma* are developed under a pair of integumentary folds placed behind the vent, forming a brood-pouch, which is developed on the under side of the tail of the female. The ova are small, measuring only about 0.75^{mm} in diameter. They are embedded in a viscid mucus contained within the pouch alluded to. A blastodisk is evidently formed in the usual way. The yolk is clear lemon-yellow in color, and its outer stratum contains small, numerous deeper yellow oil drops, the distribution of which is shown in fig. 20, plate iv. The presence of Kupffer's vesicle was not made out at this stage.

The next stage of development, which was observed in the eggs taken from the brood-pouch of another male, is represented in fig. 19, when the embryo, after being freed from the egg, measured very nearly 3^{mm} in length. This is a considerably earlier stage than that represented by fig. 1, pl. xlii, in McMurrich's paper, as the fold indicating the commencement of the formation of the caudal fin is not yet present in fig. 19. The median aorta and caudal artery extend almost to the end of the tail, where it is continued into the recurrent cava and the subintestinal vein which return the blood to the heart. As soon as the subintestinal vein reaches the posterior pole of the yolk it bends down and traverses its posterior median and anterior face towards the heart, the venous end of which rests upon the yolk. The branchial arches are formed, though there are no branchial filaments yet developed. The pectoral fin-fold is already present as a low lobular process just behind the auditory capsule. The dorsal fin is just becoming clearly evident as a low median fold behind the vent. There is as yet no trace of an anal fin-fold visible. The oil drops have a more general distribution over the yolk than in fig. 20; the head is much flexed downward, and the brain is very conspicuous. In passing I would state that in McMurrich's fig. 1 the mid-brain is identified by mistake with the cerebellum, the cerebellum is confounded with the pineal gland, while the medulla oblongata is erroneously identified with the mid-brain and medulla oblongata together.

³⁸ A. de Quatrefages. Memoire sur les embryons des Syngnathes (*Syngnathus ophidion*, Linn.), Ann. des Sci. Naturelles, xviii, 2d ser., 1842, pp. 193-212, pls. 2.

³⁹ Ryder. A contribution to the development and morphology of the Lophobranchi-ates; (*Hippocampus antiquorum*, the sea-horse). Bull. U. S. Fish Commission, i, 1881, pp. 191-199, pl. xvii.

⁴⁰ J. P. McMurrich. On the osteology and development of *Syngnathus peckianus* (Storer), Quar. Jour. Mic. Sci., xxiii, n. s., pp. 623-650, pls. 2.

A more advanced stage is shown in fig. 21, plate iv, measuring about 3.5^{mm} in length. The pectoral fin at this stage has already partially rotated on its base. The dorsal fin is more developed, while the tail begins to show signs of the development of the permanent rays from the coalescence of the embryonic rays or actinotrichia. The circulation is more developed and the blood may be seen circulating through the gill arches, but there are still no filaments formed. A more enlarged view of the head of this stage is shown in fig. 12, plate iii, where the four gill arches are more clearly indicated.

I must here take exception to certain of McMurrich's statements in his paper already cited in reference to the development of the fins. He says (p. 648): "In the young stages an anal is present, which, however, does not pass beyond the stage in which fibrillation [development of actinotrichia] begins, but aborts and is entirely wanting in the adult." This is an error, because a careful inspection of the adults of both sexes of *Siphostoma fuscum*, apparently the same species as was used in his studies, reveals a small but undoubted anal fin just behind the vent. The erector and depressor muscles are also not attached to the oval cartilaginous nodules at the bases of the fin-rays, as stated by McMurrich, but to the bases of the fin-rays themselves. This author's statement that the tail of *Siphostoma* is heterocercal at first is not borne out either by the method of development of the tails of fishes generally, or by the evidence supplied by figs. 19 and 20 of this species here given; these two stages just referred to being really much younger than any figured by McMurrich, and they serve to show that the young of *Siphostoma* pass through what I have called an archicercal stage.

A very curious and interesting morphological fact is revealed by a study of the development of the *Lophobranchii*, namely, the manner in which the neural arches are duplicated several times on each vertebral centrum. The proximal parts of the parallel cartilaginous bars supporting the rays of the dorsal fin in *Hippocampus* and *Siphostoma* afford the basis for the ossification of about five neural arches to a single centrum in the region of the dorsal fin. And, since the more anterior and posterior vertebræ also have a number of dorsal arches, it is probable that the cartilaginous rudiments of such arches are also duplicated in those regions in an analogous manner, but at a somewhat later stage of development. This peculiar method of development and duplication of the neural arches will very probably serve to distinguish the Lophobranchiates from other families of fishes.

In plate xvii of my first paper on the Lophobranchiates, cited above, I fell into an error in the identification of the cranial cartilages of *Hippocampus*, as pointed out by McMurrich. In the skull, figured on the plate indicated, the names of several cartilaginous elements must be changed. The unpaired element *sy*, given as "symplectic," must be regarded as genio-hyoid, the "element *x*" is the quadrate and pterygoid, while *a* is not "labial," but pterygo-palatine and not "ethmo-palatine,"

as it is identified by McMurrich. The element *q*, given as "quadrate," must be regarded as the symplectic portion of the hyomandibular bar.

VIII.—MONOCANTHUS BROCCUS (MITCH.) DEK. (*Fool- or File fish.*)

The eggs of this species were obtained by me from adult females captured in the pound-nets near Cherrystone, Va., about the middle of July, 1880. The eggs are quite small, and measure not quite .7^{mm} in diameter. They are very adhesive, and adhere again and again to foreign objects if detached. They are pale green in color and have a group of small refringent oil-drops embedded at one side of the vitellus. An unimpregnated egg of this species is figured on plate iii, fig. 15. The lot of eggs to which the one figured belongs was not fertilized, as far as I am aware, yet the blastodisk was very distinctly developed, as the figure shows. At the end of about two hours no segmentation was observed.

IX.—APELTES QUADRACUS (MITCH.) BREEVOORT. (*The Four-spined Stickleback.*)

For the opportunity to study the development of this interesting species I am indebted to Mr. W. P. Seal, who supplied me with developing ova and a pair of spawning adults in April, 1881, and on which I shortly after published some notes⁴¹ and observations. I kept one pair of adults which were about to spawn in an aquarium extemporized for the purpose; the male very industriously completed the spinning and weaving of a nest under my observation.

The early stages of development I did not witness, as the first lot of eggs had the blastoderm already formed and inclosing the vitellus. The lot of eggs laid by the pair in confinement were unfortunately not fertilized.

The egg-membrane is a true zona radiata, being perforated by numerous pore canals, and is covered by an adhesive material which agglutinates the eggs together into a mass to the number of 15 to 20, the number deposited at one time by the female. The ova sink to the bottom, and must be taken charge of by the male, as the female, after having discharged them, takes no further interest in their fate. The male, with his mouth, lifts the eggs into the little nest which he has prepared for their reception.

The egg of the four-spined stickleback measures about a line, or somewhat over 2^{mm}, in diameter, and are of a decidedly dark amber color. I was not able to make out the position of the micropyle. At one pole of the egg a large number of flat, button-shaped appendages are attached to the surface of the egg-membrane by means of very short pedicels, and it is in the midst of these that the micropyle is found in the European species, *Gasterosteus leiurus*, according to Ransom.

⁴¹Ryder. Notes on the development, spinning habits, and structure of the four-spined stickleback, *Apeltes quadracus*. Bull. U. S. Fish Com., i, 1881, pp. 24-29.

There is no germinal disk developed when the egg first leaves the ovary, and the cortical layer of germinal matter is uniformly distributed at first over the vitellus, which itself incloses a number of very refringent oil spheres, very variable in size. It appears that the blastodisk in this species may develop without the influence of impregnation, but no true segmentation occurs under such circumstances.

On the fourth or fifth day after impregnation the primary divisions of the brain are marked off, one of the most striking characters being the unusual spaciousness of the cerebral vesicles, the walls of the brain cavity being relatively thin when compared with those of other forms. The optic cups soon become quite deep, so that a considerable space (the vitreous humor) exists at an early period between the floor of the cup and the lens. The origin of the latter from a thickened induplication of the epiblast may be very readily traced. Some of these and other features to be described later, are represented in figs. 22, 23, and 24, plate v. Immediately behind the auditory vesicles, and shortly after their invagination, the rudiments of the breast fins appear as a pair of low longitudinal folds. In the stickleback the breast or pectoral fins develop very rapidly and while the young fish is still in the egg.

Pigment is also rapidly developed on the embryo, as is shown in figs. 25 and 26, plate v, representing the young, 6^{mm} long, of *Apeltes* when it quits the egg. During still earlier stages and while still in the egg pigment is formed so rapidly over the embryo that it soon becomes impossible to see the outlines of the viscera through the mantle of crowded pigment cells; such is the case with a still older stage represented by fig. 27, plate vi. About the time of hatching, a second kind of pigment cells, brown in color instead of black, and much larger than the latter, make their appearance. These brown pigment cells blotch the embryo symmetrically on the sides and along the median dorsal line, being confined to sharply circumscribed areas in those regions, as may be gathered from figs. 25 and 26. The style of pigmentation prevalent at the time of hatching foreshadows that of the adult.

The heart appears about the fourth day as a heap of mesoblastic cells just below the hinder part of the head, and is at first a simple sinus. It does not begin to pulsate vigorously until the seventh day, when its pulsations are nearly if not quite 100 per minute. Its venous end rapidly elongates until it extends fully the diameter of the body beyond the right side of the embryo; a large pericardial space is developed below the head at this point for its lodgment; this space dips down deeply into the amber-colored vitellus. It continues to pulsate from this time onwards, but there are as yet no blood corpuscles. A wide space now appears on the right side of the embryo and underneath the latter. This latter we may consider as a vascular sinus or channel of definite outline. The floor of this space, as far as I have been able to observe, seems to consist of the periblast (hypoblast), from which knobbed cells project upward, and which appear to be budding off portions of them-

selves, which will apparently become blood corpuscles. The sinus, at any rate, becomes much crowded with what are evidently blood corpuscles. Now follow what seem to be amœboid contractions of the yelk, or its periblastic investment, as a result of which this sinus is pushed out more to the right and over the vitellus. This sinus, as it is further extended, in a girdle-like manner, over the vitellus, as in figs. 22, 23, and 24, is seen to be obviously homologous with the edge of the *area vasculosa* of Avian embryology or to the *sinus terminalis* of the mammalian embryo. Smaller vessels are soon formed which lead from the under side of the posterior end of the embryo and join the great marginal trunk anteriorly which leads to the heart. The asymmetry of the vessels which spread over the yelk and take up its substance is very striking during the first few days of development. By the time the young fish is about to hatch the marginal sinus or trunk has gradually assumed a median position on the under side of the yelk, and small vessels pass out on either side of the body on the upper surface of the yelk in a quite symmetrical manner, as shown in figs. 25 and 26.

When the great vascular sinus or first trace of a vascular system is developed, it can scarcely be said that there is a circulation; the blood corpuscles now present are merely swayed back and forth by the pulsations of the heart. As soon as the aortic channel, underneath the chorda dorsalis, is forced through, the blood commences to pour through the sinus from the tail end of the embryo headward over the yelk, as there is now a complete and open vascular cycle of vessels developed. The cardinal and caudal veins are formed about the same time. From them the feeders of the sinus, now the vitelline vessels, are soon developed, and they are rapidly spread out over the yelk as narrow channels, becoming more and more numerous. They at first spread out over the aboral pole of the yelk, and a great common venous channel, derived from the sinus first mentioned, begins on the left side of the embryo and goes round to the right side over the yelk, like a girdle, to feed the heart. Into this somewhat tortuous, equatorial, vascular girdle the blood pours from the small veins traversing the yelk. The main vessel is symmetrically disposed in reference to the median plane of the embryo, and is gradually swung round over the yelk in front of the head as in fig. 24. Eventually the venous end of the heart is also swung round, and is pushed out under the front of the head instead of extending outwards over the yelk at one side of the head. The arrangement and changes undergone by the omphalomesenteric vessels of the embryo stickleback are characteristic, and have not been met with, as far as I am aware, in the embryos of any other Teleosts.

Kupffer's vesicle was found to be present. The urinary bladder occupies the usual position; it is large and inclosed by a proper cellular wall. The course of the intestine, when the embryo is nearly ready to hatch, is marked by a greenish color. The hind gut, during the earlier stages of development, is decidedly swollen and has a spacious lumen.

The blood becomes red in color before the embryo leaves the egg. The vascular system is better developed in this species at the time of hatching than in any other known to me, as well-defined vascular loops already exist in the dorsal and ventral median fin-folds. The branchial vessels, arches, and opercula are also in an advanced condition of development at this period, unusually so when compared with the embryos of most other forms at the same stage.

Lateral sensory or segmental sense organs are developed on the skin at the time of hatching. If the young fish is allowed to assume its normal position in a live-box, and the microscope applied, looking down past the sides of the body from above, certain thickenings of the epiblast or integument will be noticed. These thickenings are surmounted by transparent cells which project freely for a little distance from the general level of the surface. The outer ends of these cells, ten or twelve in number, are somewhat separated from one another, and have blunt truncated tips which are not surmounted with sensory hairs or filaments. The segmental sense organs of the lateral line in the young stickleback, therefore, differ very widely from those of the cod. Fig. 27 represents an older larva in which the lower lobe of the tail is beginning to develop.

THE SPINNING HABITS OF THE ADULT MALE DURING THE BREEDING SEASON.

It has been known for a long time that the males of the different species of sticklebacks build a nest in which they place the eggs laid by the females. The water is continually forced through the mass of eggs by the male fish, which moves his fins for the purpose, and also draws or pumps the water through the clump of eggs with his mouth in executing the movements of the jaws, gills, and opercula incident to respiration. Just how the nest was built, however, never seems to have been observed until about 1879 or 1880, when Mr. W. P. Seal noticed that the nest was built of threads drawn out through an opening near the vent of the male, and that the latter wound these threads round the cluster of weeds chosen to support the nest in a wonderfully intelligent manner. Specimens with which this gentleman kindly supplied me in 1881, upon dissection, showed that there was present, lying on the right side of the rectum, a large sack filled with a viscid secretion, and that this was the source of the material of which the threads were formed. These observations, which were published four years since, have apparently been overlooked by Möbius,⁴² who has recently given an account of his observations on the spinning organs of *Spinachia vulgaris* Flem., though his observations are far more complete than were my own.

On the habits of the male *Apeltes*, I wrote as follows in 1881: "The male binds the nest together by means of a compound thread which he

⁴²K. Möbius. Ueber die Eigenschaften und den Ursprung der Schleimfäden des Seestichlingsnestes. Arch. f. mikr. Anat., xxv, 1885, 1 plate. Also, Die Niere des männlichen Seestichlings, eine Spinnndrüse. Biolog. Centralbl., v, 1886, pp. 647-648.

spins from a pore or pores behind the vent, while he uses his bobbin-shaped body to insinuate himself through the interstices through which he carries his thread with which he binds a few stalks of *Anacharis* or other water-weeds together, bringing in his mouth every now and then a contribution of some sort in the shape of a bit of a dead plant or other object, which he binds into the little cradle in which the young are to be hatched. The thread is spun fitfully, not continuously. He will go round and round the nest for perhaps a dozen times, when he will rest awhile and begin again, or turn suddenly round and force his snout into its top with a vigorous plunging motion, as if to get it into the proper shape. Its shape is somewhat like an inverted truncated cone; an opening is left at the top through which it is supposed that he introduces the eggs. The thread is wound round and round the nest in a horizontal direction in the case we are describing, and if this thread is placed under the microscope when freshly spun it is found to be composed of very thin transparent fibers to the number of six or eight; where they are broken off or terminate they have attenuated tapering ends, as though the material of which they were made had been exhausted when the spinning ceased. Very soon after the thread is spun particles of dirt adhere to it and render it difficult to interpret its character. I have seen the thread being drawn out from the abdomen repeatedly, but not from the vent; it appeared to me more probable that it came from the openings of a special spinning gland. Its glass-like transparency shows that it is not made up of ingested food, the particles of which would exhibit themselves were that the case. The nest measures half an inch in height and three-eighths in diameter.

"Upon opening the male I find a large vesicle filled with a clear, extremely viscid secretion which coagulates into threads upon contact with water. This vesicle appears to open directly behind* the vent, separately from the latter. It measures one-fifth inch in length and an eighth in diameter. As soon as it is ruptured it loses its transparency, and whatever secretion escapes becomes whitish after being in contact with water for a short time. This has the same tough, elastic qualities as when spun by the animal itself, and is also composed of numerous fibers, as when a portion is taken which has been recently spun upon the nest. The nature of the opening was not learned with precision, as I possessed only a single specimen. The vesicle lies to the right side of the intestine, and there is very little doubt that it opens behind the anus. The testes are two ovoid glands, the ducts of which unite into a common canal, both glands and ducts being covered with black pigment cells; the testes, during the breeding season, measure somewhat less than an eighth of an inch in length. As to the origin of the secretion I have

* By mistake it is stated, in this paragraph of my original account, that the sac opens "in front of the vent." I make the needed correction here, as I find that the sketches which I made at the time show that it opened behind the vent, as stated in the first paragraph.

no suggestion to make, but there are certain glandular structures lying close by, the significance of which I am at a loss to understand."

Since the above was written the inspection of additional material enables me to state that the secretion is present only during the breeding season.

Möbius has investigated the subject much more thoroughly in the larger European stickleback, *Spinachia vulgaris*, and he finds that the sac, found by me in *Apeltes* to be filled with a viscid secretion, is really the urinary bladder. And, further, that the sources of the viscid secretion are the kidneys, the secretion being poured out from the epithelial cells of the uriniferous tubules. The bladder acts simply as a reservoir in which it accumulates. In *Spinachia* the threads measure 0.12 to 0.13^{mm} in diameter, the male winding them around weeds to form a nest, in the same manner as the male of *Apeltes*. The secretion or viscid spinning material belongs, according to Möbius, to the mucines. Boiling hydrochloric acid stains it a violet color and then dissolves it. Nitric acid stains it yellow but does not dissolve it. It is insoluble in acetic acid; soluble in caustic potash solution, and when in solution in the latter, if acetic acid is added drop by drop, a white precipitate is formed, which is again dissolved if acetic acid is added in excess. Boiling baryta-water dissolves it, but boiling lime-water does not.

Möbius traced the secretion to the epithelial cells lining the urinary tubules of the kidneys or wolffian bodies. After the breeding season the volume of the kidneys and urinary bladder diminishes, and they then contain urine only, while during the breeding season they are principally filled with the slimy secretion, the thread being spun from the genito-urinary opening just behind the vent.

X.—*ESOX RETICULATUS* LE SUEUR. (*Common Eastern Pickerel; Green Pike.*)

From material supplied by Mr. W. P. Seal, I am enabled to give figures of two stages of this type; the youngest 9^{mm} long and the most advanced 11.5^{mm} in length. These are represented by figs. 28 and 29.

The young of this species become pigmented rather soon. The gill arches remain exposed for a considerable time, as is shown in fig. 29, in which the depressed, produced snout characteristic of the pike family is also already evident. Caudal metamorphosis is also beginning to manifest itself in this older stage, the tail having become lancet-shaped, and proportionately narrower than in the younger stage preceding. There is a well-developed vitelline circulation which has been figured by Truman⁴³ in the embryo of *Esox lucius*. The same species has also been investigated by Swirski,⁴⁴ who has worked out the devel-

⁴³E. B. Truman. Observations on the development of the ovum of the pike, Monthly Mic. Journ., Oct., 1869, pp. 185-203, pls. 27-29 and part of 30.

⁴⁴Georg Swirski. Untersuchungen über die Entwicklung des Schultergürtels und des Skelets der Brustflosse des Hechts. Inaug. Diss., Dorpat, 1880, pp. 60, pls. 2.

opment of the skeleton of the shoulder-girdle and pectoral fins of this type. The most important contribution to our knowledge of the development of fishes of this type, however, is a paper by Walther.⁴⁵

It is interesting to note that Swirski found no less than fifteen cartilaginous nodules at the distal ends of the still cartilaginous actinosts or basipterygial pieces, of which he finds four, but the distal end of the fifth and most dorsal in position is bifurcated, showing that it is probably compound, having doubtless originated by the proximal coalescence of two parallel bars. Some of the distal nodules or actinophores were transitory. The sixteen or seventeen rays of the pectoral developed as do those of the rays of the median fins, viz, by the proximal concrescence or blending of horn fibers or actinotrichia. The large number of pectoral actinophores found at various stages would indicate, even if two rays must be reckoned to a segment, that at least eight metameres have thrust processes of tissue into the pectoral fold during its development. These data seem to indicate, in fact, that considerable reduction has occurred in the number of metameric elements in the paired fins of Teleosts, since certain of these elements are transitory.

Walther's paper discusses especially the chondrocranium and the relation of the cementum plates, at the bases of the conical enamel-crowns of the teeth, to the formation of the membrane bones of the jaws and mouth.

X.—SPECIES No. 1.

This fresh water species, which I cannot identify, has a very adhesive egg, 1.6^{mm} by 1^{mm} in diameter, as shown in fig. 31, plate vii. The blastoderm constricts the yolk in a very remarkable way during its growth over the yolk-globe, as shown in figs. 30 and 31. A very large refringent oil-drop is embedded in the yolk; the larger oil-drop is also surrounded by a wreath of much smaller ones. Kupffer's vesicle is developed under the tail end of the embryonic axis in the stage represented by fig. 33. Fig. 32 represents nearly the same stage in profile, and shows the oil-sphere pushed quite to the ventral and anterior pole of the yolk, where it remains until absorbed, as shown in fig. 34.

Three days after hatching, the embryo measures about 4^{mm} in length, has a well-marked vitelline circulation developed, and a row of dark pigment spots are developed along the side of the body, while a very singular and peculiar arrangement of pigment is found on the yolk-sack. On the latter, as may be seen in fig. 34, the pigment spots are confined to the points where the minute vessels join each other.

These eggs were found adherent to a piece of leather in a single layer at Havre de Grace, Md., in the early part of May, 1881. The adhesive

⁴⁵Johannes Walther. Die Entwicklung der Deckknochen am Kopfskelett des Hechtes (*Esox lucius*). Jenaische Zeitschr., xvi, n. f., ix, 1. und 2. Heft, Jena, 1882, pp. 69-87, pls. iii-iv.

agglutinating matter which covered the zona radiata seemed to have flowed down over the egg and hardened into a kind of flat disk at one side, as shown in fig. 31. The yolk is quite transparent, but the disk and blastoderm are rather thick; these characters lead me to think that it is the egg either of a Cyprinoid or a Centrarchid, most probably the latter, as the yolk of the Cyprinoids is generally very granular.

XI.—PERCA AMERICANA SCHRANCK. (*Yellow Perch; American or Ringed Perch.*)

I have not yet had an opportunity to study the development of this valuable fresh-water species, which spawns in April and May. Like the European *P. fluviatilis*, it lays its eggs in flat bands consisting of a single layer, agglutinated together by an adhesive material. These flat bands of eggs somewhat resemble those of the goose-fish or *Lophius*, but they are not as large and do not float on the surface as do the egg-ribbons of the latter; on the contrary, in this species, they are quite heavy and sink to the bottom, and are suspended by the female in all probability upon submerged objects where they are left to hatch out.

The envelopes of the eggs of the yellow perch are, however, so complex in structure that they may be recognized with the greatest readiness. The vitellus measures 1.75^{mm} in diameter. It contains a large oil-sphere which occupies an eccentric position. The oil-sphere is not represented in fig. 35, plate viii, representing the egg of the American perch, which measures, including the spacious and thick-walled egg-membrane, 3.5^{mm} in total diameter.

The egg-membrane is exceedingly complex, and consists apparently of an internal layer, *z*, which is homologous with the zona radiata of other types. Immediately overlying the zona there is a very thick, highly elastic layer, *g*, which is traversed radially by fibers or canals which widen perceptibly at the outer surface. A third thin investment, *a*, overlies this thick elastic layer, and it consists of the hardened mucine-like material which agglutinates the eggs together. At one point on the surface of the egg there is a wider pore canal which leads to the micropyle *m*. The outer layer, *a*, serves to agglutinate the egg to the outer layer of adjacent eggs, as shown in fig. 35.

XII.—ROCCUS AMERICANUS (GMEL.) J. & G. (*White Perch.*)

The eggs of this species are quite small and measure only about .73^{mm} or one thirty-fourth of an inch in diameter, are very adhesive and stick together in masses or in thin layers over fixed objects in the water. The zona radiata is quite thick and is traversed by fine pore-canals. The micropyle is a minute opening measuring .0075^{mm} in diameter. Externally the zona radiata is at first covered by a thick layer of adhesive matter, which flows toward the points where the eggs come into

contact with a foreign body or with each other. At such points disk-like hardened accumulations of the adhesive investment of the egg are developed, as shown in figs. 36 and 37, plate viii. The oil-drop in the vitellus is relatively quite large, as an inspection of the figures named will show.

The blastodisk is also quite bulky in comparison with the bulk of the yolk, as is indicated by the stippled areas, showing the blastodisk in optical section, in figs. 36 and 37. When the blastoderm is developed and has spread over one-half of the yolk, as shown in fig. 38, it is characterized by its great thickness and its much swollen rim. The yolk is also more or less constricted at a later stage by the rim of the growing blastoderm, in the same way as shown in figs. 30 and 31. The embryo, before the tail begins to grow out, embraces considerably more than half the circumference of the yolk. Kupffer's vesicle is also developed at this stage, or by the time the condition shown in fig. 39 is reached.

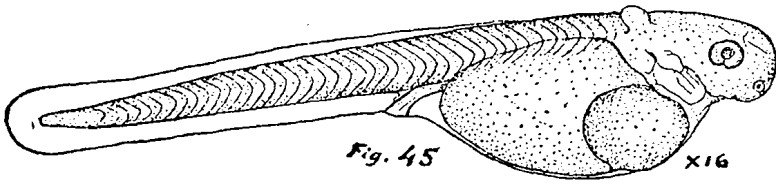
In six days, with the water at a temperature ranging from 51° to 53° Fahr., the young fish leaves the egg. Viewed as a transparent object, the young White perch at the time of hatching presents the appearance represented in fig. 40, when it measures 2.3^{mm} in length. No fin-folds have as yet appeared and the head seems as if it almost formed a continuum with the yolk-sack below it. On the first day after hatching considerable growth is made by the embryo, since it now measures somewhat over 3^{mm} in length. This stage is represented by fig. 41, plate ix. At the end of three days but little more growth has been made, as is shown in fig. 42, but after the young fish has been hatched five or six days, as shown in figs. 43 and 44, the head begins to project forward. The oil-drop now occupies the forward part of the yolk-sack and is covered by cells derived from the periblast. Stellate pigment cells also begin to make their appearance at this time over the oil-drop, and a few scattered ones develop on the sides of the tail and back part of the yolk-sack.

During the later stages the yolk-sack becomes more elongated, and the liver develops as a bud-like outgrowth from the ventral wall of the mesenteron. The rudiments of the pectoral fins appear as a pair of low horizontal folds of the larval integument some distance behind the ear-capsules. The mouth is barely more than indicated at this stage of development. The spawning season of this species is in April and May.

XIII.—STIZOSTEDIUM VITREUM (MITCH.) JORDAN AND COPELAND. (Wall-eyed Pike.)

The eggs of this species measure nearly a line in diameter or nearly 2^{mm} . Shortly after hatching, the embryo measures 5.8^{mm} (see fig. 45). The pectoral fin is already developed and the oil-drop is anterior in position as in the embryos of the preceding species. The eggs and embryos

observed by the writer came from Northville, Mich., and were hatched on the 15th of June, 1885, at the Central Station, Washington.



XIV.—SCOMBEROMORUS MACULATUS (MITCH.) J. & G. (*Spanish Mackerel.*)

Figs. 46 to 56, plate x, relate to this species and give a few details of structure which it was not possible to work out by the methods of study which I was obliged to pursue at the time my first paper was written.

Fig. 46 represents a transverse section through the first cerebral vesicle; the nasal pit is also cut through at *na*. Fig. 47 represents a section through the mid-brain and the origin of the optic nerves. A segmental sense organ is also cut through just above the front portion of the eye. Fig. 48 is from a section a little farther back than the preceding. Fig. 49 is a very much enlarged representation of a section through one of the segmental sense organs, showing the columnar character of the cells of the lower layer of the integument in these structures. Fig. 50 is a representation of a section cutting transversely through the hinder region of the mid-brain and shows the course of the fibers of the optic nerves through the retinal walls. Fig. 51 represents a cross-section through the fore part of the medulla oblongata; a segmental sense organ is also shown in section. Fig. 52 represents a cross-section cutting through the auditory capsule *au*, with a segmental sense organ, *ss*, below it; below the pharyngeal region, in the middle line, the bulbus arteriosus and ventricle is cut through. Fig. 53 represents a longitudinal section of a young Spanish mackerel somewhat off the median line. Above the pericardial cavity *pe* the branchial and hyomandibular arches are cut across. The heart *h* opens directly, as in fig. 56, into the space surrounding the periblast *p*, as I have elsewhere described in the embryo of *Clupea*. The trabeculae cranii *tr* are seen to be feebly developed at this stage, as shown in both figs. 53 and 56. Fig. 54 represents a cross-section through the pectoral fin-fold *p'*, the yolk-sack, and segmental ducts *sd*. The periblast in this section is seen to be well developed and contains nuclei. Fig. 55 represents a cross-section through the tail of a young Spanish mackerel, a segmental sense organ having also been cut through. Fig. 56 shows that the oil-drop *o*, at the posterior end of the yolk, is mainly enveloped by the periblast. The intestine *i* is cut through at several points, and the segmental duct *sd* of one side is split lengthwise, the section passing through the urinary

bladder *al* and the pronephric funnel *pn* anteriorly. The chorda *ch* is cut through at several points, and the floor of the pericardial cavity *pc* is shown to be very thin and continuous with the venous end of the heart *h*. The latter, therefore, opens directly into the body cavity behind it, the body cavity itself being directly continuous with the cleavage cavity of an earlier stage, the latter becoming the former in the course of development. These sections were prepared from Spanish mackerel embryos which had left the egg only about twenty-four hours, and measured about 3^{mm} in length.

XV.—*CHÆTODIPTERUS FABER* (BROUSS.) J. & G. (*Angel-Fish; Porgee, or Moonfish.*)

The ova of this species are pelagic or floating in habit, in sea-water having a specific gravity of 1.014. They hatch out in twenty-four hours when the temperature of the water is 80° Fahr. This species spawns in the Chesapeake during the latter part of June and the early part of July. It is prodigiously fertile, the female probably discharging a million ova during a single season.

The egg measures somewhat over a millimeter in diameter. The blastodisk will develop independently of fertilization, as shown in fig. 57. Cleavage is very rapid and it requires only about one hour to pass from the condition shown in fig. 58 to the morula condition shown in fig. 60. Fig. 59 shows the form assumed by the cells of the morula stage, and traces are also present of the subquadrate form assumed by the blastodisk at the time of the completion of the second cleavage.

After the blastodisk begins to spread, the development of the marginal cells at its edge becomes very well marked, as shown in fig. 61. The oil-drop, shown in figs. 58, 60, and 61, remains for a time almost exactly opposite the center of the blastodisk, and later, when the embryo is formed, it occupies a median ventral position in the yelk-sack, as shown in figs. 62 and 63, and is not finally shoved to the posterior end of the latter, as in the embryo Spanish mackerel.

In thirteen hours the embryo fish is fairly outlined, as shown in fig. 62, and the oil-drop becomes covered by the periblast in which nuclei seem to be differentiated. At this stage faintly-colored pigment cells, mostly of a rounded form, become developed on the body of the embryo. At the under side of the tail Kupffer's vesicle is also distinctly developed. All over the blastoderm, enveloping the yelk at this stage, faintly-colored pigment cells are discernible.

At the end of twenty-four hours the young fish leave the egg, measuring about 2.5^{mm} in length. Sixteen hours later, as shown in fig. 63, the embryo has grown about half a millimeter in length, and the greater part of the yelk has been absorbed, so that an immense serous space is left in front of the yelk, between the periblast enveloping the latter and the outer somatopleural sack. This wide space has

been derived directly from the cleavage cavity. By this time the pigment cells on the body and tail have begun to aggregate in definite groups, as shown in fig. 63, and the majority have also become distinctly stellate.

Fig. 64 represents the recently-hatched moonfish. The body cavity *sc*, formerly the cleavage cavity, is already very spacious, as the yelk is being absorbed more rapidly than the outer somatopleural envelope of the yelk is collapsing. This outer somatopleural covering of the yelk in this species, as in all young fishes, even Elasmobranchs, is quite free and is not fused with the periblast-splanchnopleure beneath it. The oil-drop, it will also be noticed, is now invested by distinct cells of periblastic origin, which have well-defined borders, and are more or less stellate. It also bulges outward, more or less distinctly, but it is easy to see that it is still invested by the yelk. The pectoral fin-fold appears far behind the auditory involution in the stage represented by fig. 64; it is somewhat more developed in the more advanced stage represented by fig. 63. The ventral fins appear quite late, as they were absent in the oldest stages observed by me.

Twenty-eight hours after hatching, the young moonfish measures 3.5^{mm} in length, and presents the appearance shown in fig. 65. Embryonic fin-rays have by this time made their appearance at the end of the tail; the pectoral fin is well developed, and the intestine is longer and the urinary bladder is larger. The yelk has also diminished greatly in size, and the mouth will soon be open. There is still no complete circulation, though all the principal subdivisions of the heart are developed and that organ is pulsating vigorously. By this time traces of a reddish pigment begin to appear on the upper and lateral portions of the abdomen.

Fifty-three hours after hatching the young moonfish has grown mainly in height of the body, as shown in fig. 66. The snout is very blunt and declivous and foreshadows the form of the blunt, rounded profile of the parent fish. The yelk is nearly absorbed and over the abdominal walls there is now developed a strongly-marked group of stellate red pigment cells. A flexure of the intestine is also developed and the urinary bladder is very large and distinct. The pectoral is strongly developed and a complete circulation is apparent, though the aorta bends upon itself and is continued forward against the caudal vein at a point less than half the distance between the vertical from the vent and the end of the tail. The pigment cells have also by this time been more definitely aggregated into a definite band on the tail and on the integument above the pectoral. The young fish by this time measures nearly 4^{mm} in length.

I have seen some of the post-larval stages of the young of this species in Chesapeake Bay measuring from one-half to one inch and a quarter in length. In these the transverse dusky bands seen in the adult are intensely bluish-black in color. It is, therefore, obvious that the color-

ation diminishes greatly in brilliancy with age. I have very strong reasons to suspect that the larvæ of this species are phosphorescent at night.

XVI.—GADUS TOMCOD WALB. (*Tom-cod; Frost-fish.*)

The eggs of this species of Gadoid are somewhat larger than those of the common codfish. The egg-membrane is rather thick and tough and is covered externally by an adhesive coating of a mucine-like substance which agglutinates the eggs together in masses, the latter being very frequently, if not usually, attached to sea-weeds and stones at the bottom of the littoral zone. The eggs are not pelagic, like those of the cod, though there is a very conspicuous oil-drop in the vitellus; as development progresses this oil-drop is pushed forward to the anterior pole of the yelk-sack.

When hatched the gape of the mouth is very much greater than that of the larva of the common cod. The intestine terminates at the margin of the ventral fin-fold, instead of some distance from it, as in the larval cod, as may be seen by comparing figs. 1 and 67. There is no integumentary vesicle or bulla developed over the head as in the young cod, so that the larval stages of this species differ very widely from its congener, though both spawn in winter or during the colder months of the year. The larvæ of the tom-cod are also more robust in build than those of the cod, and measure at the time of hatching very nearly, if not quite, 5^{mm} in length.

XVII.—CLUPEA SAPIDISSIMA WILSON. (*The Common Shad.*)

The interest attaching to the development of this species is two-fold, namely, that which appeals to the economist and that which appeals to the biologist. While the description of the morphological changes which this species undergoes during development will be of immediate interest only to the latter, the former, if he be a fish-culturist, and not otherwise interested in the life-history of the type under consideration, may still perhaps derive useful information from what is to follow respecting the manner in which the perpetuation and development of this valuable food-fish is accomplished. With the invention of greatly improved appliances, the hatching of this form from artificially fertilized eggs is now accomplished to the number of perhaps fifty to seventy millions annually along the Atlantic slope, reckoning in this total the combined efforts of the United States and the different State fish commissions of the coastwise States. The species is anadromous and quite fertile, a single female yielding during the season, if unmolested, about 200,000 ova. These ova are probably discharged in shoal water and mainly after night-fall. Spawning occurs during the spring months of April and May, and as late as June and July in the latitude of Washington and Baltimore.

The freshly-extruded egg of the shad is of a very pale amber color, and is invested by a very much wrinkled *zona radiata*, as shown in fig. 68. At this time, if the egg is allowed to lie on a plane surface, its form is considerably flattened, and its outline from above is subquadrate and irregular. The freshly-laid egg, if examined with a low power of the microscope, is found to be very closely invested by the *zona radiata* *z*, fig. 69; immediately below the *zona* lies the cortical layer *cl*, in which numerous minute rounded bodies or corpuscles are imbedded. This cortical layer of plasma also sends down into the yolk thin laminar prolongations of itself which envelop the large yolk masses *y* into which the body of the vitellus is subdivided. Immediately after the ova are brought into contact with the sperm or milt of the male shad a great change in their appearance occurs. This change consists mainly of the distension of the wrinkled *zona* with water, as a result of which the egg becomes spherical, its bulk at the same time becoming about seven times greater than in the unimpregnated state. This change may occur in the presence of water without the agency of impregnation, but it is then not apt to affect all of the ova in this way. As a result of the distension of the *zona radiata* or egg-membrane, the latter is lifted up from contact with the surface of the vitellus so that it lies quite free in its spherical envelope with a wide space all around it, as shown in fig. 70, in which the vitellus is shown as an oval black dot and the contour of the egg-membrane as a simple circle. This figure represents the egg of the shad of the natural size with the vitellus lying in the lower half of its envelope. With the further progress of development no additional distension of the egg-membrane occurs, but during the whole of the time the space surrounding the egg or embryo remains the same, as may be seen by reference to fig. 101, plate xvi; figs. 126 and 127, plate xviii; and fig. 136, plate xix.

Upon the impregnation of the egg, which is effected by the entrance of a spermatozoön through the single minute pore or micropyle, which admits of the passage of the male element to the vitellus from the outside through the *zona*, a germinal thickening of the cortical layer or a blastodisk is rapidly developed. In its natural position in the *zona*, the vitellus of the shad, surrounded by its envelope of germinal matter, assumes the form of an oblate spheroid or that of a somewhat flattened sphere, when viewed in optic section, as shown in figs. 71, 72, and 73. At first there is no blastodisk present, but a few minutes after impregnation the cortical layer at one side of the ovum becomes perceptibly thicker over one pole of the vitellus by the concentration or aggregation of its substance at that point, as shown in profile in fig. 71, and from above in fig. 75. The substance of the cortical layer becomes slowly heaped up after impregnation into a depressed conical mass at one pole of the vitellus, as shown in figs. 71, 72, 73, 74, and 76. Normally, the blastodisk is lateral in position when the egg is at rest. From its inferior side strands of protoplasmic matter pass down between the large

vitelline masses into which the yelk is subdivided. These strands of plasma radiate from the under side of the blastodisk into the yelk somewhat in the same way as the roots of a plant radiate from the base of its principal stem into the surrounding soil, as is shown in figs. 71 to 78, inclusive, plate xiv.

In the course of about fifteen minutes after fertilization, I have several times witnessed the expulsion of the polar cells from the developing blastodisk of the ovum of the shad. A distinct prominence is first developed near the center of the thickening of the cortical layer, as shown in fig. 74. At intervals of a minute or so apart, the changes which that prominence undergoes I have represented in fig. 79, *a, b, c, d, e, f*. The two polar cells at first lie close to the surface of the incipient disk; later, they remain adherent only by a slender filament of protoplasm, as shown at *c*. Finally, they are detached from the filament, as shown at *d*, and at last the filament itself is slowly withdrawn into the cortical layer, disappearing entirely at a stage a little more advanced than that shown at *f*. The polar cells in this species are finally detached, and seem to disintegrate in the large water space surrounded by the zona, and in which the egg lies. Such a detachment of the polar cells is not without precedent, for Bischoff represents them as detached in the segmenting ovum of Mammalia, and I have myself observed their detachment from the segmenting ova of Nudibranchiate mollusks, and saw them drop into the perivitelline space just as seems to be the case in *Clupea*.

At the end of about half an hour, with the water at a temperature of 75°, the blastodisk is formed, and at the end of one hour and twenty minutes the first cleavage furrow has been formed. This furrow divides the blastodisk into two equal conical masses, as shown in figs. 77, 78, and 80. These figures represent the cleavage in its most active phase, when the plasma of the disk is heaped up into two remarkably prominent blunt cones. The disk becomes much elongated as a result of the development of the first cleavage, nor does it lose its elongated squarish form for a considerable time after the second cleavage furrow is developed, as shown in fig. 81, from above, and in figs. 82 and 85 in profile. Certain irregularities of cleavage are sometimes apparent, such as the development of five cells in the disk at this stage, instead of four, or the normal number. An abnormal disk of this kind is represented in fig. 83. The second furrow is developed about two hours after fertilization.

Upon the advent of the third set of furrows, which divide the four cells of the last stage transversely, the blastodisk is subdivided into eight cells lying in two parallel rows of four each, as shown in figs. 86, 87, and 88. The third set of furrows appears about half an hour after the second cleavage has been completed. In the course of the next forty minutes the thirty-two celled stage of segmentation has been passed over, as represented in figs. 84, 89, and 90. The morula condi-

tion is now entered upon, but its development is not completed until about four to five hours after fertilization. Consequently, the next change which the blastodisk undergoes is the further subdivision of its component cells. Just after the stage represented in fig. 90, the blastodisk becomes divided into two layers of cells, as shown in fig. 91. At about this time the nuclei of the periblast become sundered from the nuclei of the cells at the edge of the blastodisk. The morula stage is finally completed when the segmented blastodisk assumes in section the lenticular form represented in figs. 92, 93, and 95; nuclei are already apparent in the periblast of the latter.

Immediately succeeding the morula stage comes the blastula condition, when, for the first time, the blastodisk becomes markedly lifted up at its center from the underlying periblast. As a result of this lifting up of the middle of the blastodisk, which at the same time becomes thinner in the center, a space appears under its central part, known as the cleavage cavity, as shown in figs. 137 and 138, plate xix. The duration of this phase of the blastula is brief and is almost immediately followed by the gastrula stage.

The advent of the gastrula stage is characterized by the inflection of the margin of the blastoderm. This becomes greatly thickened at one point at its margin, or where the future embryo will be formed, as shown in optic longitudinal section, in fig. 137, at *s*, as a swelling. Other views of this stage are also given in figs. 138 and 139. At this time the cleavage cavity has a kidney-shaped outline as viewed from above, but it soon becomes somewhat crescent-shaped, as in fig. 140, for the swelling *s* of the previous stages is extending inwards to form the embryonic shield *e*. In sagittal, optic section this same stage is represented in fig. 141, with the egg in another position. Both these last figures were carefully drawn from micro-photographs.

The gradual advance of the blastoderm over the vitellus is represented by figs. 140 and 141, plate xix; fig. 96, plate xv; figs. 118, 119, and 120, plate xvii; and in figs. 98, 101, and 102, when the yelk-blastopore or protostoma of the egg of the shad may be said to have closed, the margin of the spreading blastoderm being considered the margin of the gastrula mouth and the whole yelk as hypoblast, together with the formative hypoblast *h*, as shown in figs. 96 and 118. Such an arrangement causes the gastrula mouth from *o* to *o* to be greatly expanded or widened in order that it may embrace the greatly hypertrophied hypoblast with its inclusions of passive deutoplasm.

Before the blastoderm of *Clupea* begins to spread a well-defined thin cuticle or epidermis is developed over its whole surface, composed of a single layer of squamous cells, as shown in fig. 95. This is the first differentiation of tissue layers which occurs in the blastodisk of the ovum, aside from the formation of the periblast. As a result of the inflection of the margin of the blastoderm, the hypoblast and epiblast are developed, the former from the inflected stratum of cells, *h*, and the the

latter, *e*, from the epithelial and immediately underlying cells of the disk. From these two primitive organs all those of the young shad are evolved by further differentiation, folding, expansion, invagination, &c.

The central nervous system is developed wholly from the epiblast. This will be rendered the more obvious from a glance at figs. 106 to 108, representing transverse sections through the embryonic axis of an embryo shad represented in fig. 101, plate xvi. The spinal cord *N* in these is shown to arise as a thickening of the layer *e*, and extends the entire length of the body at this stage, and is here characterized by its solidity, as in the embryos of all Osseous fishes and the Lampreys. During a later stage the cord *N* becomes separated from the layer *e*, as is shown in cross-sections (figs. 109 to 112) of a much later stage, viz, that shown in fig. 126, though the sundering of the embryonic spinal cord from the epiblast in reality occurs considerably earlier, or by the time the stage represented in fig. 103 is reached.

As the blastoderm spreads, the portion *e*, fig. 140, lengthens to form the embryo, the component layers of the latter, fig. 96, *e* and *h*, becoming much thickened in the vicinity of the median longitudinal plane. From the inferior thickened part of the inflected band of tissue *h*, the chorda *ch*, figs. 106, 107, and 108, is formed, together with the myoblasts or myotomes on either side of the chorda, as dorsal outgrowths, fig. 97, *M M M*, of the primitive hypoblast *h*. These rudiments of the musculature of the body in the embryo shad are not hollow, as in *Branchiostoma*, or composed of two layers forming the inner and outer walls of the series of myoblastic segments, as in *Elasmobranchii*. They are therefore not clearly defined paired archenteric diverticula or gut pouches, but their solid condition is probably due to an abbreviation of development like that which has affected and retarded the appearance of the cavity of the spinal cord and brain and that of the intestine. The inferior part of the layer *h*, in fig. 96, gives rise in the middle line to the intestine *i*, as shown in figs. 106 and 107. The lumen of the intestinal canal appears very slowly, and at first is a mere pore in cross-sections, as shown in figs. 109 to 112 at *i*. During the early stages the hypoblastic band which gives rise to the intestine is thickest at the posterior end of the embryo, and gradually thins out and widens as it extends toward the head. This is rendered obvious upon comparing a section near the tail end of the embryo, fig. 111, with a more anterior one, fig. 109, from the region of the back part of the medulla oblongata. The lumen of the intestine in this anterior region is also no longer pore-like, but flattened, cleft-like, and transverse.

At a slightly earlier stage than is shown by the sections represented in figs. 106 and 107, the chorda *ch* is found to be united inferiorly with the layer *i*, which gives rise to the intestine. The chorda, myotomes, and the intestine are therefore to be regarded as differentiations of the layer *h* in figs. 96 and 118.

The myotomes gradually increase in number, and at the time the blastopore closes but three or four are visible, as shown in fig. 120. Somewhat later more are added behind those already formed, as shown in figs. 98, 101, 102, 103, 123, 126, 127, until the full complement is developed, as shown in fig. 151.

Of the sense organs, the optic lobes, from which the eyes are formed, are the first to become developed. These appear as a pair of lateral elongated thickenings of the epiblast at the front end of the embryonic axis. Four stages of the differentiation of the optic lobes are shown, as viewed from the above, in figs. 114 to 117. These phases of the development of the eyes and head may be readily connected with the more advanced ones represented in figs. 113 and 128.

The gradual extension of the cleavage cavity *sc* under the growing blastodisk may be traced by reference to figs. 137, 138, 139, 140, 141, 118, 119, 120, 121, 98, 102, 103, 122, 126, and 127. After the entire yolk is covered by the blastoderm the only cellular membranous covering investing it externally is the extremely thin epiblastic membrane *e*, shown in section, fig. 121, and between this and the periblast *p* of the same figure the cleavage cavity *sc* is included; this again being directly continuous with the body cavity *bc* on either side of the intestine *i*. This relation of the surrounding parts to the cleavage cavity demonstrates very conclusively that the membrane *e*, in fig. 121, must be the somatopleure, while the periblast *p* must undoubtedly be homologized with the splanchnopleure. The vascular network developed over the periblast and in intimate connection with it, in the ova of many species of fishes, is also splanchnopleural and homologous with the area vasculosa or omphalomesaraic meshwork developed over the yolk of higher forms. Of the correctness of this homology I think there can scarcely be any doubt whatever.

The yolk of *Clupea*, and of Teleost embryos generally, it may therefore be said, is intra-abdominal; it is excluded from direct connection with the intestine, but remains adherent to it for a considerable time by its inferior face, through the intermediation of the periblast immediately underlying the intestine. The yolk is almost naked were it not for the thin syncytium, known as the periblast, and which, on the lower and lateral portions of the yolk, can hardly be considered to rank as a true membrane on account of the widely-scattered or diffused nuclei it contains. The splanchnopleure (= periblast) of osseous fishes is therefore rudimentary or very feebly developed over the vitellus, so that the latter may be considered to be intra-abdominal, not only because there is no umbilical stalk developed, but also because it is very imperfectly inclosed by the splanchnopleure.

The chorda is unusually well developed in *Clupea* and forms a massive axial rod at the time of hatching, as shown in cross-section at *ch*, fig. 121, and for its whole length in fig. 148. Derived as already stated from the median dorsal part of the hypoblast, it retains its con-

nection with the last-named layer longest at its posterior extremity, as shown in fig. 98. After the tail begins to bud out, however, its intimate connection with the hypoblastic layer is broken, and it then terminates after becoming somewhat enlarged in the cellular terminal mass in which the lateral myoblastic *m*, neural *N*, and post-anal section of the gut *i* terminate, as shown in cross-section in fig. 104, and in vertical and transverse optic section in figs. 103 and 113. The histological differentiation of the chorda has already been described by Kupffer, Kowalevsky, and others, so that there is no occasion for me to redescribe it, as it takes place in very nearly the same way in the embryos of all *Chordata*. The cells of the chorda of *Clupea* are, however, unusually large and contain very spacious cavities, in which no coagulable albumen is present.

The later stages of the development of *Clupea* involve mainly the completion of structures, the rudiments of which were laid down during the evolution of the stages already described.

The renal apparatus of the larval shad is extremely simple, and consists, at the time the tail begins to bud out, of a pair of parallel tubes differentiated from before backwards from the outer portions of the mesoblast at the time it splits into somatopleure and splanchnopleure. The segmental ducts *sd* finally lie just above the somatopleural peritoneum and extend from a little way behind the pectoral plate *pp*, fig. 113, or the pectoral fins, fig. 148, to a point just behind the vent where they debouch into a common cavity, the urinary bladder which opens outward behind the vent. At their anterior extremities the segmental ducts terminate in a single nephridial funnel which opens into the body cavity, the mouths of the pair of funnels being directed backward and inward, so that the anterior extremities of the ducts are bent upon themselves in the form of a shepherd's crook.

The development of the cranium is not precocious, and its primary cartilaginous elements are not very apparent until after hatching. The most obvious portions are the trabeculæ *Tr*, figs. 142, 143, and 144, the branchial bars *i*, *ii*, *iii*, *iv*, and *v*, and the hyomandibular arch, composed of the hyomandibular *Hm*, interhyal *Ih*, quadrate *Q*, symplectic *Sy*, Meckel's cartilage *Mk*, and the cerato- and glosso-hyal elements *Ch* and *Ch*. The auditory vesicles *Au* are quite large, but are not entirely invested by cartilage; only the outer and inferior aspects being closed in by chondrified tissue, as shown in cross-section in fig. 147, which was prepared from a larva about six days old. Fig. 144 represents a very nearly mesial longitudinal section through the head of a just-hatched larva, in which the positions of the cranial cartilages crossing the middle line are indicated. Fig. 143 represents the cranial cartilages of a slightly older larva constructed from a series of sections. Fig. 142 represents the cranial cartilages of a still more advanced larva, in which the antorbital process *Ao* and trabecular rostrum *R* are more strongly developed. The branchial and hyomandibular arches have also reached a considerably greater development than in the preceding

stage, while the anterior end of the notochord has become more completely covered by the parachordal cartilages. This inclosure of the anterior extremity of the chorda by the parachordal elements *pa* is more distinctly displayed in figs. 146 and 147, plate xxi, drawn from cross-sections of the same stage as that represented by fig. 142. The tegmen cranii *Tc*, fig. 142, is not developed during the earlier stages, shown in figs. 143 and 144. The palatopterygoid is not present until the stage represented by fig. 142 is attained, or perhaps even later. An element which I identify as palatopterygoid is present in the cross-section represented in fig. 145, and has been cut through just below the eye at *pt*. This element, at any rate, seems to be developed quite independently of any connection with the hyomandibular.

The heart at the time of hatching opens directly into the cleavage cavity (=body cavity), as represented in fig. 144, and it is not until some days after hatching that connection is established between its venous end and the jugular and portal veins *jj'*, and *pv*, as shown in fig. 152. The yelk seems to be absorbed by the heart and portal vessels, which pass above it, and its anterior end is finally drawn out into a pointed process, which is directed toward the heart, as shown in fig. 152. I have witnessed the budding of free cells from the periblast *p* in the stage represented in fig. 144, and have, also, seen such cells pass directly into the cavity of the heart, though there was, as yet, no complete circulation.

The other visceral organs are differentiated as appendages of the alimentary canal. The first and most conspicuously developed is the liver *L*, figs. 133, 148, 150, and 152, it being formed as an outgrowth of the ventral wall of the intestine. Just a little distance behind the posterior extremity of the liver, the alimentary canal is constricted at *py*; this marks the point just behind which the pyloric appendages will grow out. Just in advance of the pyloric constriction, and on the dorsal side of the œsophageal portion of the alimentary canal, the air-bladder grows out as a saccular diverticulum of the intestinal wall at *ab*, fig. 133. The first traces of the air-bladder do not appear until some days after hatching, and the same may be said of the gall-bladder *Gb*, fig. 133, which is formed at the anterior end of the liver. In the course of about three weeks the metamorphosis of the visceral organs is nearly completed, as may be gathered from fig. 131, as this figure represents the pneumatic duct *pn*, posterior end of the œsophagus *oe*, the rudimentary stomach *st*, and the pylorus *py* of a young shad nearly an inch long and three weeks old, reared in confinement. There are still no pyloric cæca, but the permanent form of the alimentary tract of the Clupeoids is already very clearly apparent.

We may now review the principal and most striking changes in external form which the young shad undergoes within the egg. Starting with the phase represented in figs. 137, 138, 139, 140, and 141, when the first trace of the embryo becomes obvious at one side of the blasto-

derm the embryo is finally quite distinctly outlined when the stage represented in figs. 101 and 102 is reached. A little later the tail begins to bud out as shown in fig. 103. Later still, and usually by the end of the second day, the young fish has reached the condition represented in fig. 126. Somewhat later the stage represented in fig. 127 is attained. The yolk is still quite large at this time and the peritoneal or segmentation cavity *sc* is obvious. At this time the horizontal folds which give rise to the pectorals appear, as shown in fig. 128 from above and in diagrammatic section in figs. 129 and 130. A more advanced stage of the development of the pectoral fin is represented in fig. 134, at which time it begins to be rotated on its own base. As a result of this rotation, its posterior or metapterygial border becomes directed downward, while its anterior or propterygial border is directed upwards or dorsally. Shortly after the stage represented in fig. 136 is reached the young fish leaves the egg. By the time this stage is reached the mouth is open, but there is no open or free passage through the œsophagus. The gill and hyomandibular arches are obvious, though the branchial clefts are still very narrow. After hatching, as shown in fig. 149, the tail of the larva is perfectly lophocercal and shows no well-marked signs of heterocercality until some time after the absorption of the yolk. The larva now measures 10^{mm} in length. Fig. 148 represents a stage about two days older than that shown in fig. 149, and in which the gill-arches and jaws are more fully developed, so that the mouth is opened and closed voluntarily by the young fish. A feeble branchial respiration is established about this time. The auditory vesicles are now fully differentiated and the semi-circular canals, otoliths, and auditory end-organs of the seventh nerve are developed as shown in fig. 132. Two pairs of recurved teeth have also been developed in the lower jaw at this stage.

At the end of about the fifth day the yolk has been almost entirely absorbed; only a small fusiform mass of vitelline matter, *Y*, fig. 151, remains and causes the ventral wall of the abdomen to bulge downwards behind the pectoral fins. By this time the mesoblast begins to proliferate into the median dorsal fin-fold to form the foundation of the permanent dorsal, as indicated at the base of the widest portion of the dorsal fold in fig. 151. On the thirteenth day a decided notch at the posterior end of the future dorsal, as shown in fig. 133, marks the point in advance of which that fin will be formed. In the course of twenty-one to twenty-eight days the young shad has about completed its metamorphosis, when it is still much slenderer than the adult, though it has all of the fins developed, even the ventrals, which grow out quite late and about midway between a vertical passing through the pectorals and another passing through the anus. In six months the larvæ of the shad, if kept where they can find an abundance of small crustacea, insects, &c., will grow to a length of 4½ inches. By the time they reach that size they are readily recognizable by their external characters as appertaining to this species.

The gill-clefts remain uncovered for a long time, as shown in figs. 150, 151, and 153, but by the twenty-first to the twenty-eighth day the opercular folds have grown to such an extent that the clefts and gills are quite concealed from observation externally. When the fish reaches that stage of development it measures 22^{mm} in length, or not far from an inch, and has a heterocercal tail in which the permanent rays are well developed, as they are in all of the fins except the ventrals. The first obvious intimation of heterocercality in the larval shad appears on the seventeenth day, as shown in fig. 150, representing a rather stunted larva measuring 14^{mm} in length. The food during the later larval stages does not accumulate in the stomach, but accumulates in the intestine *I*, just behind the pylorus, as shown in fig. 150. It is only after the young fish acquires mobility of its jaws that it begins to feed, and after the small teeth already mentioned have appeared; indeed, the larvæ about this time occasionally become so ravenous that they have been known to attempt to eat each other, and finally strangle in their efforts at consummating cannibalism.

The temperature at which the ova of the shad develop normally ranges from about 55°, or perhaps slightly less, up to about 80° Fahr. Experiments made to determine the lowest temperature at which normal development would take place gave some very interesting results. It was found that at a little below 52° Fahr. abnormalities of various kinds were sure to appear. Some of these I have figured from micro-photographs on plate xviii. Figs. 122 and 123 show how the development of the tail and notochord was impaired when the embryos were subjected to a temperature ranging from 45° to 48° Fahr. Fig. 124 shows how the development of the blastodisk became impaired when subjected to the same low temperature.

A great variation in the period of hatching of this species is caused by variations in the temperature of the water during the hatching season; for example, at 74° Fahr. hatching occurs in about seventy hours; at 64.5° Fahr. in one hundred and nine hours; at 57.2° Fahr. in one hundred and forty-eight hours or over six days. I have known it to require seventeen days for the ova of the shad to hatch when the average temperature of the water was 53.75° Fahr. In ordinary pleasant spring weather the eggs usually hatch during the third or fourth day after fertilization.

The first paper of note on the development of the shad was published by the late Prof. H. J. Rice⁴⁶ in 1878. Since then the writer has published additional observations⁴⁷ on the development and the retardation of the development of the eggs and on the feeding⁴⁸ of this species.

⁴⁶H. J. Rice. Notes upon the development of the shad (*Alosa sapidissima*?). Report of a Commissioner of Fisheries of Maryland, January, 1878, pp. 95-106, pl. vi.

⁴⁷J. A. Ryder. On the retardation of the development of the ova of the shad. Bull. U. S. Fish Com., i, 1881, pp. 177-190 and 422-424.

⁴⁸J. A. Ryder. Observations on the absorption of the yolk, the food, feeding, and development of embryo fishes. Bull. U. S. Fish Com., ii, 1882, pp. 179-205. One figure in text.

The illustrations accompanying the present note on the development of *Clupea sapidissima* have been drawn in part with the camera lucida at various times during the last five years; a number are redrawn from a series of very successful micro-photographs made by Mr. T. W. Smillie, under the direction of the author.

XVIII.—*ICTALURUS ALBIDUS* (LE SUEUR) J. & G. (*White Cat-fish*;
Channel Cat of the Potomac.)

I have already given a short account of the development of this species elsewhere,⁴⁹ but as the many remarkable phases presented by its larval growth cannot be understood without illustrations, I will now give a fuller and more detailed description, with such figures as are ready for publication.

A number of individuals of this Siluroid were brought from the Potomac River to the Armory Building in the spring of 1883, and deposited in the large aquaria in that institution at about the close of the shad-hatching season of that year. One pair of these fishes afterward spawned while in confinement, and thus afforded the writer the opportunity of observing and describing some of the more interesting phases of development of this singular family of fishes. There has hitherto been little attention paid to the development of this type, probably from the lack of opportunity; and these notes may therefore prove of interest to naturalists. The literature of the subject is scanty; and, besides a paper by Jeffries Wyman⁵⁰ on the development of *Aspredo lœvis* and *Bagrus*, I know of no separate essays on the development of this group, except some remarks in Günther's Introduction to the Study of Fishes, and in his article Ichthyology, ninth edition of the Encyclopædia Britannica, on the development of *Arius*. An egg of this genus is there figured in an advanced state of development, from which it appears that this form is very similar in its embryological features to *Ælurichthys*, some ova of which are in my possession, measuring three-fourths of an inch in their longest and five-eighths of an inch in their shortest diameter. *Arius* and *Ælurichthys* are marine forms, and the males have the habit of carrying the ova in the hinder part of the oral cavity or branchial region until the young are hatched. These marine species, however, have only a few very large ova so concealed in the mouth of the male at one time. They are probably far less prolific than the species the development of which is about to be described.

The adults were kindly identified for me by Professor Gill. Its habits of spawning and care of the young are probably characteristic of all of the species of the genus, of which there are said to be eight found within the limits of North America.

⁴⁹ J. A. Ryder. Preliminary notice of the development and breeding habits of the Potomac cat-fish, *Amiurus albidus* (Le Sueur) Gill. Bull. U. S. Fish. Com., iii, 1883, pp. 225-230.

⁵⁰ J. Wyman. On some unusual modes of gestation. Am. Journ. Arts and Sciences, xxvii, 1859, pp. 5-13.

On the morning of the 13th of July, a little after 10 o'clock, we noticed a mass of whitish eggs in one of our aquaria inhabited by three adult specimens of *Ictalurus albidus*, two of which were unmistakably the parents of the brood, for the reason that they did not permit the third one to approach near the mass of eggs which one of them was watching vigilantly. One of the individuals remained constantly over the eggs, agitating the water over them with its anal, ventral, and pectoral fins. This one subsequently proved to be the male and not the female, as was at first supposed. The female, after the eggs were laid, seemed to take no further interest in them, the whole duty of renewing and forcing the water through the mass of adherent ova devolving upon the male, who was most assiduous in this duty until the young had escaped from the egg-membranes. During all of this time, or for a period of about a week, the male was never seen to abandon his post, nor did it seem that he much cared even afterwards to leave the scene where he had so faithfully labored to bring forth from the eggs the brood left in his charge by his apparently careless spouse. The male measured 15 inches in length, the female a fourth of an inch more.

On the 30th of June, or when the young were seventeen days old, it was determined to make an examination of the internal organs of both parents, which was done in the presence of Professor Gill, to learn which one of the parent fishes it was that had acted as nurse. Fortunately there was considerable difference between the two in color; the female had also lost a part of one maxillary barbel, so that it was easy to distinguish the two fishes apart. The darker specimen, with the broader head, we found was the male, which, as already stated, had acted as the nurse. Upon cutting him open and removing a portion of the milt or testes they were found as a lobulated pair of organs, lying one on either side of the mesentery and depending from the dorsal wall of the abdominal cavity. The lobes of the testes were digitate. Upon compressing fragments of the testes under the microscope, active spermatozoa were passed out. The spent roe or ovary of the female was a paired organ, the right and left sacs of which were joined together posteriorly. The ovarian lobes or leaflets were disposed transversely in the sacs.

The mass of ova deposited by the female on the 13th of July in one corner and at one end of the slate bottom of the aquarium measured about 8 inches in length and nearly 4 inches in width, and was nowhere much over one-half to three-fourths of an inch in thickness. There were probably 2,000 ova in the whole mass, as nearly as could be estimated. The single ova measured about one-sixth of an inch in diameter a short time after oviposition.

The ova were covered with an adhesive but not gelatinous envelope, so that they were adherent to the bottom of the aquarium and to each other where their spherical surfaces came in contact, and consequently had intervening spaces for the free passage of water, such as would be

found in a submerged pile of shot or other spherical bodies which had been piled in a heap. It was evident that the male was forcing fresh water through the interstices in this mass of eggs by hovering over it and vibrating the anal, ventral, and pectoral fins rapidly.

All of the ova left in the care of the male hatched, while about one-half of the mass which he had detached from the bottom of the aquarium on the third day, during some of his vigorous efforts at changing the water, were transferred to another aquarium, supplied with running water, and left to themselves. Those which were hatched by the artificial means just described did not come out as well as those left to hatch under natural conditions. Nearly one-half of the former failed to hatch, apparently because they were not agitated so as to force fresh water through them and kept clean by the assiduous attentions of the male parent.

The eggs measure about one-sixth of an inch after the large water space is formed, which is normally developed in this, as in the ova of other fishes, after fertilization, the zona radiata being lifted up somewhat from the vitellus. The vitellus measures one-eighth of an inch in diameter. The egg-membrane is double, that is, there is a thin inner membrane representing the zona radiata, external to the latter and supported on columnar processes of itself which rest upon the inner membrane; there is a second one composed entirely of a highly elastic adhesive substance. The columns supporting the outer elastic layer rest on the zona and cause the outer layer to be separated very distinctly from the inner one. It is these elastic columns and the elastic outer adhesive membrane which permits the adult fish to shake and move the mass of ova so violently without injury to the embryos in process of development within. This peculiar double egg-membrane, with a well defined space between its inner and outer layers, is highly characteristic, and bears no resemblance to the thick, simple zona investing the egg of *Atlurichthys*, nor has anything resembling it ever been described, as far as I am aware, in the ova of any other Teleostean.

The germinal disk was formed at the upper pole of the vitellus immediately after oviposition and gradually spread in the usual manner over the lower pole of the opaque, whitish, granular, vitelline globe. In the early part of the second day the body of the young fish was distinctly outlined and the tail had grown out to a considerable length, and before the body of the embryo had encircled much more than one-fourth of the circumference of the vitellus, as shown in figs. 154 and 155—the first figure being drawn from a hardened embryo of the second day, viewed as an opaque object and the second from a living embryo of the same age, viewed as a transparent object. On the third day, the tail of the embryo had acquired considerable length, as shown in fig. 159, and its free extremity was moved from side to side grace-

fully and rhythmically through the contents of the water space surrounded by the zona.

The water space from the first was filled with an immense number of free refringent but very minute corpuscles, which made it difficult to make out the form of the embryo during the early stages, unless the zona was first removed. These corpuscles were not of the nature of blood cells, and seemed to become less abundant toward the close of the period of development within the egg. So abundant were these corpuscles at first, coupled with the opacity of the vitellus and the peculiar whiteness of the germinal matter, that even an experienced observer would be led to suppose at first that all of the eggs were bad, having the "rice-grain" appearance of blasted shad ova. The corpuscles mentioned are visible in sections of the entire egg of *Ictalurus*, and are very abundant in the water space forming adherent masses. In life the movements of the tail of the embryo cat-fish whirl these corpuscles about in the water space in clouds, so that it seems as if a whitish sediment was being constantly stirred up within the egg-membrane. The presence of vast numbers of such bodies of plasmic origin within the egg-membranes of Teleosts it seems had not been observed in any other form up to the time that the writer had published his observations on the development of the cat-fish. Recently, however, it has been found by Solger⁵¹ that they are present in the water space of the ova of other species, especially of *Leuciscus rutilus*. These corpuscles becoming less abundant toward the close of the hatching period is very probably to be accounted for on the supposition that they are taken up and appropriated by the epiblastic tissues of the embryo by a process of intracellular digestion.

On the third day the vascular system begins to be evident, and the heart *h*, figs. 156 and 157, is extended forward beneath and in advance of the head over the anterior end of the yolk. A pair of vascular arches (Cuvierian ducts) are soon formed just in advance of the rudiments of the pectorals. These vessels grow outward and split up into vitelline capillaries and eventually join a median ventral vitelline vessel which empties into the venous end of the heart, as shown in figs. 163 and 164.

The mouth is not yet open on the second day, fig. 155, but at this stage if the embryo be removed from its envelope and viewed as an opaque object, the rudimentary branchial arches and clefts, fig. 154, *b*, are visible. The first traces of the pectoral thickenings or outgrowths *p*, in advance of the lateral extensions of the muscular somites of the body, are evident at this stage. The eyes *e*, fig. 154, are unusually small for young fishes at this stage, and remind one of the comparatively small eyes of embryo sturgeons, bony gars, and amphibians. The choroid fissure is prolonged obliquely downward and forward on the second day, as shown in fig. 155.

⁵¹ B. Solger. Dottertropfen in der intracapsulären Flüssigkeit von Fischeiern. Arch. f. mik. Anat. xxvi, 1885 pp. 321-334.

On the third day the mouth is wide open, figs. 156 and 157, and the branchial clefts *b*, fig. 158, are developed with a free circulation through the arches. The opercular folds *op*, fig. 159, which lead to the formation of the opercles of the adults, are also beginning to be quite obvious. The caudal part of the aorta and caudal vein are also developed at this stage, and the intersegmental vessels are formed a little later, from which loops run out into the mesoblast of the median fin-folds.

The pectoral fin is formed as a lateral outgrowth *p*, figs. 158 and 159, just in advance of the inferior and lateral extension of the muscular segments *m m*, which eventually form the muscular portions of the lateral body-walls. In this early condition the pectoral is a mere flat, immobile lobe, into which muscular and other mesoblast has proliferated; it also begins to show evidences of a slight rotation or torsion on its own base. At its base and a little way toward the middle line of the embryo there is a patch of thickened epiblastic tissue composed of very large cells. This is the rudiment of a peculiar integumentary organ, situated in the adult above the base of the pectoral and behind or upon the shoulder girdle, and is composed of a series of vesicular cavities which contain particles of calcareous matter.

The development of the median fins is very similar in character to that usually observed in other forms. On the second day the median natatory fold began to grow out on the dorsal and ventral sides of the embryo and over the end of the tail. By the end of the third day the median fin-fold was well developed, and the tail had not yet exhibited any inclination to become heterocercal.

The remarkably developed barbels of the embryos of this species make their appearance very early, especially the maxillary pair; these appear on the second day as a pair of bosses or thickenings of the epiblast at points near where the future angles of the mouth will be situated. On the third day this pair of barbels is developed as flat prominent lobes *bl* at the angles of the mouth, as shown in figs. 156, 157, and 158. The barbels on the lower jaw do not appear till the fourth day of development is completed, as shown in fig. 152. The last of all to be developed is the nasal pair, which grow out at the anterior side of the posterior nareal openings, as shown in fig. 164; this pair does not appear until the seventh day. The development of a cartilaginous axis in the barbels takes place as early as the formation of the other portions of the chondro-skeleton, but the fuller description of these supports of the barbels will be postponed until I come to the account of the cartilaginous cranium, with which the cartilages found in the barbels are in intimate relation.

The nasal pits, or the first traces of the olfactory organs of *Ictalurus*, appear on the second day as a pair of thickenings of the epiblast, just in advance of the eyes. On the third day they are visible as a pair of much antero-posteriorly elongated depressions or pits, in the same location, as shown in fig. 160. On the fourth day the edges of the elon-

gated olfactory depressions begin to grow toward each other in the middle, and by the fifth day a bridge is formed across the nasal sack, so that an anterior and posterior opening is left, corresponding to the anterior and posterior nostril of the adult.

Hatching occurs on the sixth day, at which time the embryo presents the appearance shown in fig. 163, when viewed as a transparent object. It now measures 9^{mm} in length, or somewhat over a third of an inch. The heart is now prolonged downward over the anterior pole of the yelk. The branchial arches are quite hidden by the downward and backward extension of the opercular folds. The tail has also become decidedly heterocercal, and distinct indications of the future permanent caudal rays are developed. The anterior dorsal fin is also becoming evident, just behind the head, where mesoblast has begun to proliferate into the median dorsal fin-fold.

On the seventh day, as shown in fig. 164, the fins have undergone still further development. The pectoral has completed its rotation, and the anterior dorsal and the anal fins are outlined. The caudal lobe is wider and its rays more evident. The entire set of four pairs of barbels is also now evident, and a more intricate meshwork of vessels traverses the surface of the yelk.

On the eighth day, as shown in fig. 165, the yelk has diminished somewhat in size. The anterior dorsal is now also sharply defined, and some distance behind it the dorsal fin-fold is widening at the point where the second or soft dorsal will be formed. The ventral fins have also appeared as a low horizontal fold at the ventral side, between the vent and the yelk-sack. The rudiments of permanent rays are also evident in the pectoral.

On the ninth day, as shown in fig. 166, the ventral is a more pronounced lobe than on the preceding day, but no rays have yet made their appearance. The upper or first ray of the pectoral is also now developed as a spine, and the position of the soft dorsal is indicated by a decided notch at its posterior extremity.

On the tenth day the permanent rays of the dorsal become clearly defined, as shown in fig. 167, and the ventral has become somewhat more prominent. The yelk is now rapidly disappearing, and by the eleventh day comparatively little is left to distend the abdomen, as may be noted in fig. 168, representing a young *Ictalurus* of that age. At this stage the rays of the ventral begin to be apparent, while those of the pectoral, dorsal, anal, and caudal are clearly differentiated; accessory caudal rays are also beginning to be formed, and the nasal barbel is conspicuous.

On the fifteenth day all of the fins are well developed and permanently outlined, but the lower lobe of the caudal is still shortest, as shown in fig. 169. Five days later the lower lobe of the caudal is somewhat longer, as shown in fig. 170. The anterior spinous ray of the first dorsal and of the pectoral is now developed, and the latter has assumed a

nearly horizontal position. The young *Ictalurus* is now twenty days old and would be readily recognized as possibly belonging to one of several American genera, though at this stage it resembles most nearly the adult of the genus *Noturus*, indicating that the latter is a less specialized type than the one here under consideration.

When the young *Ictalurus* is eighty-eight days old, as shown in figs. 171 and 172, from the side and from above, its external generic features become distinctly apparent. The anterior dorsal spine and the pectoral spines, armed posteriorly with recurved hooks, are now developed. The post-scapular process is evident beneath the skin and the air bladder forms a strongly marked rounded prominence just behind the shoulder-girdle, where it presses the body-wall outwards. The soft dorsal is now quite free and sharply defined posteriorly, and the pigmentation, which has gradually increased in depth since the time of hatching, is now very nearly that of the adult. At this stage of development the young fish measures 19.5^{mm} in length. At the end of one hundred and twelve days the young of *Ictalurus*, measures 25^{mm} in length, or about 1 inch. When one hundred and seventy days old the young fish measures 35^{mm} in length. These two stages I have not figured, since the resemblance to the adults is sufficiently obvious in fig. 171, representing a much younger individual. The young of *Ictalurus* therefore more than double their length in eighty-two days, and nearly quadruple it in one hundred and sixty-four days after hatching, as the foregoing data demonstrate.

On the fifteenth day after oviposition it was found that the young fishes would feed. While discussing with the writer what should be provided for them Mr. J. E. Brown threw some pieces of fresh liver into the aquarium, which they devoured with avidity. It was now evident that they were provided with teeth, as they would pull and tug at the fragments of liver with the most dogged perseverance and apparent ferocity. This experiment showed that the right kind of food had been supplied, and as they were then fed, up to August 1, with nothing else without our losing a single one of the brood, nothing more in the way of food seemed to be required.

It is worthy of note that when pieces of liver were thrown into the aquarium the parent fish would apparently often swallow them, with numbers of his offspring eating at and hanging to such fragments. I was soon agreeably surprised to find that the parent fish swallowed only the meat, and that he invariably ejected the young fish from the mouth uninjured, as he seemed to be able to discriminate, instinctively and before deglutition occurred, between what was his proper food and what were his own young. As soon as the young began to feed they commenced to disperse through the water and to all parts of the aquarium, and to manifest less desire to congregate in schools near the male, who also abated his habit of fanning the young with his fins, as was his wont during the early phases of development.

The air-bladder became perceptible through the semi-transparent bodies of the young on the tenth day, as a dorsal outgrowth of the back part of the œsophagus, and is placed far forward, a little above and behind the level of the insertion of the pectoral fins, and as it grew more capacious the young fish commenced to swim higher in the aquarium. When first hatched, and for some days afterwards, the young fish exhibited a great tendency to gather together in a dense school.

Of the development of the viscera I shall have but little to say at present. The intestine is not prolonged backwards very far beyond the posterior end of the yelk-sack. On the thirteenth day the greenish secretion of the liver can be seen in its cavity.

The liver is developed on the ventral side of the intestine and very soon displaces, more or less extensively, the coarsely granular yelk below it. It is crowded into the anterior end of the yelk-sack close to the heart, at first growing downward and outward on the left side as a rather elongated structure lying between a vertical traversing the hinder part of the opercles anteriorly and a vertical cutting through the shoulder girdle posteriorly. A capillary network of vessels traverse the liver and pour their contents directly into the vitelline or portal system of vessels which convey the blood back to the heart.

Behind the vent a distinct urinary duct could be seen by the sixth day, and by the tenth day the urinary bladder was developed in the usual position in the extreme hinder portion of the body cavity and just behind the posterior section of the gut. The renal apparatus was present and had reached an advanced stage of development on the tenth day, urinary tubules and glomeruli being found in advance of the air-bladder, and also behind it.

In the upper posterior part of the gill-cavity of either side a large glandular organ is found on the tenth day, which is undoubtedly the thymus gland; it is embedded only in the posterior part of the upper wall of the gill-chamber.

The air-bladder is formed as an outgrowth of the dorsal wall of the fore-gut. The saccular diverticulum, from which this organ is formed, acquires a lumen about the fifth day after the commencement of development, and on the tenth day the organ presents the form of a depressed oval sack. By the twentieth day the hinder end of the air-bladder becomes emarginate and shows traces of the bilobed character which it presents in the adult. By this time also the muscle plates overlying its exterior right and left aspects have aborted more or less completely, so that its walls come into close juxtaposition with the integument just behind the shoulder girdle.

The cranium of *Ictalurus albidus* when ten days old I have figured on plate xxx. At this time its principal elements are represented by cartilage, though the membranous representatives of parostoses are rapidly developing external to the chondrified parts. None of these have been represented in fig. 173. This drawing was made from a series of

superimposed outlines of the cartilages of the skull, as cut at successive levels in a series of sections of uniform thickness, extending from the outer side of the head to the middle line. Stereograms of this character may be readily constructed with the aid of the camera lucida from a series of sections, if a uniform amplification is employed and patience and care is exercised in drawing the outlines.

It will at once be noticed that, as compared with the chondrocranium of *Salmo*, as figured by Parker,⁵² or of *Gambusia*, as figured by myself,⁵³ the cartilaginous cranium of *Ictalurus* presents some very important modifications. These involve mainly the structure of the palatopterygoid arch *PlPt*, which is composed in *Ictalurus* of two pieces instead of one. The narrow bar *T Cr*, representing the tegmen cranii in *Ictalurus*, is much wider in both the other types named, and the build of the skull in the type here described is complicated by the presence of no less than three pairs of cartilaginous appendages for the support of the barbels, representing chondrified elements which are probably not found in the skulls of young fishes of any other type. The skulls of the *Nematognathi* are therefore distinguishable from those of other ordinal groups of fishes at a very early period of development.

The chondrocranium of the young *Ictalurus*, as a whole, is depressed, but relatively far less so than in the adult. The auditory apparatus is quite completely covered in laterally and inferiorly by a cartilaginous investment in the region marked *Au*. Below and mesially, the parachordal elements *Pa C* are found, although now quite completely fused with the auditory capsules laterally and the trabecular bars *Tr* anteriorly. The cartilaginous brain box is perforated laterally on either side in the exoccipital region to give passage to the ninth and tenth pairs of nerves at IX and X. In advance of the articulation of the hyomandibular bar, *Hm*, there is a large lateral fenestra in the cranial box through which the second or optic, the fifth or trigeminal, and the seventh or facial nerves pass at II, V, and VII. Just in front of this is the orbit *O*, and forming its lower inner walls is seen the chondrified plate *Ps* destined to form the presphenoid. In front of the orbit there is a high ectethmoidal ridge, *EE*, in advance of which lies the olfactory fossa *Ol*. Anteriorly the skull terminates in the trabecular rostrum *R*. There is a wide fontanelle behind the tegmen cranii or frontal bridge, and a smaller one in front of it. These fontanelles persist in the median line as narrow clefts, partly separating the frontals in the ossified cranium of the adult. At the posterior end of the cranial box and in the median line, the supraoccipital, *so*, is developed as a separate block of cartilage. The extent to which the chorda is prolonged into the base of the skull is indicated by the dotted line below the auditory capsule *Au*.

⁵² W. K. Parker and G. T. Bettany. Morphology of the skull, London, 1877, p. 59, fig. 17.

⁵³ J. A. Ryder. Development of Viviparous Oss. Fishes. Proc. U. S. Nat. Mus., 1885, pl. x, pp. 150-151.

The appendicular skeleton of the cranium, or the cranial visceral arches possessing endoskeletal supports, are apposed to the infero-lateral parts of the skull at the anterior part of the auditory region.

The most important of these arches is the compound hyoid and mandibular, supported by a common hyomandibular element, *Hm*, which abuts with its upper end upon the anterior wall of the auditory capsule. Inferiorly the hyomandibular gives support (1) to the mandible, now entirely constituted of Meckel's cartilage, *Mk*, but around which articular, angular, and dentary parostoses are subsequently laid down in membrane; and (2) to the hyoid arch, through the intermediation of a short cylindrical element, the interhyal *I Hy*, which in its turn supports a series of elements consisting of the ceratohyal *C Hy*, hypohyal *H Hy*, and urohyal *G Hy*.

The changes which the hyomandibular has undergone in the course of further development are quite complex. The principal portion of the upper half becomes the ossified hyomandibular element of the adult, an articular knob being formed on its posterior border, which supports the operculum. Its inferior half represents the quadrate of authors. Between the quadrate and hyomandibular portion the cartilage representing the symplectic does not seem to be well distinguished. The inner, upper, anterior part of the hyomandibular bar takes part in the formation of the hinder part of the pterygoid, *i. e.*, the metapterygoid of the adult. The ecto- and entopterygoid are apparently differentiations of the posterior separate element of the palatopterygoid arch *Pl Pt*.

The branchial arches are five in number; the posterior is imperfectly developed above. At the inner ends of the posterior branchial bars are placed a pair of epipharyngeal plates, *Phb*, bearing teeth even at this early stage. The branchial bars are not yet definitely segmented into their lateral elements. Cartilaginous copulæ or basibranchials, *B B*, are present in the floor of the branchial region, as shown in section in fig. 174.

A very remarkable series of cephalic appendages now remains to be described. These are the maxillary, nasal, and mental barbels. Of these the nasal pair only is not represented in cartilage at the stage of development here under consideration, but even this one develops a chondrified axial support at a later stage.

Whether the endoskeletal part of the upper end of the so-called maxillary barbel in reality represents the maxillary bone of other fishes seems somewhat open to doubt, as the proximal ossification of the cartilaginous support of this barbel would give this element in the catfishes a cartilaginous origin, which is at variance with what is known of the development of its homologue in all other forms of Teleosts, in which it arises as a membrane bone. True, it ossifies on the surface of the cartilaginous support of the barbel, even in *Ictalurus*, yet it is barely

possible that the so-called adnasal of McMurrich,⁵⁴ may, if not actually a part of the suborbital chain, as he surmises, in reality represent the maxillary of other fishes, since this adnasal element is clearly a membrane bone, while it is not altogether certain that the so-called "maxillary" of the *Nematognathi* can be considered such. While the ossification of the upper end of the cartilaginous bar *Mxb* is superficial, old specimens of *Ictalurus* show that the cartilage is invaded and replaced by the process, so that its terminal portion only remains cartilaginous. The other barbels, viz, the nasal and the mental, are also occasionally ossified at the base, especially in old specimens. Both the internal pair of mental barbels *Ib* and the external pair *Eb* are at first laid down in cartilage in the embryo. The strongest argument in favor of regarding the ossified basal parts of the lateral barbels as maxillary elements is derived from a study of the distribution of the branches of the fifth group of nerves as worked out by Wright,⁵⁵ though it must not be forgotten that these organs in Siluroids are specialized as tactile organs, and that they may therefore be richly supplied with nerves, in correspondence with their high degree of specialization.

A longitudinal, median, vertical section through the head of *Ictalurus* is represented in fig. 174, prepared from an embryo of the same age as that used in working out the cranium represented in the preceding figure. The brain is shown in mesial section and illustrates the relations of the cerebrum *Cer* anteriorly to the pineal body *Pn* just behind it. The narrow midbrain *mb* is also shown, and upon which the remarkably voluminous cerebellum *Cb* encroaches from behind. At an earlier stage the great antero-posterior width of the cerebellum is far less obvious, so that it is quite clear that the excessive anterior extension of the cerebellum in the Siluroids is a result of the exaggerated development or specialization of this portion of the brain of the ordinary Teleostean type. The medulla oblongata *mo* is massive. The infundibulum *Inf* departs but little in its form from that usually met with in the embryos of osseous fishes. The cranial nerves and brain of *Amiurus* has been so carefully described by Wright (*op. cit.*) that no further discussion of this part of the subject will be entered upon here, except to call attention to the disposition of the sacculus vasculosus *S* and the hypophysis *Hy*.

A mesial section of the heart is also displayed in fig. 174. The thin-walled sinus venosus *SV*, the muscular ventricle *Vc*, and the bulbus aortæ *Ba*, have been cut through. The tip of the liver *L*, crowded into a cavity in the coarsely granular yolk *Y*, is also shown, together with the more homogeneous periblast *P*, which invests the mass of granular deutoplasm. The granules of deutoplasm in the yolk-sack are characteris-

⁵⁴ J. P. McMurrich. Osteology of *Amiurus*, Proc. Canadian Inst. Toronto. N. S., ii, No. 3, p. 278, pl. ii, fig. 1, *An*.

⁵⁵ R. R. Wright. On the nervous system and sense organs of *Amiurus*. Proc. Canadian Inst. Toronto. N. S., ii, No. 3, pp. 366-368, pl. iv.

tically firm in character, but globular instead of flattened and oval or elongated, as in the ova of Ganoids, Amphibians, and Elasmobranchs.

The muscular bundles *MM*, cut through at several points, actuate or belong to the pharyngeal, branchial, submaxillary, and hyoid regions of the head. The intestine *I*, œsophagus *Oc*, and air-bladder *Ab*, are cut through in the middle line in the section here represented. The anterior part of the chorda *Ch* has also been divided in the middle line, and the rudiments of the three anterior centra *xxx* are seen to be shorter than those which follow. Two of these centra eventually coalesce with each other, and with the fourth and fifth form the co-ossified anterior segment composed of four vertebral bodies in the spinal column of the adult. Some of the lateral processes and parts of the neural arches of these co-ossified vertebræ, especially the first, second, and third, give rise, according to McMurrich, to the series of ossicles by which the air-bladder and auditory apparatus are brought into intimate physiological relations with each other.

The development of the shoulder girdle is remarkable from the circumstance that the coracoid portion originally laid down in cartilage is excessively developed, extending downward as a great flat cartilaginous blade, *Cor*, from the base of the pectoral fin, as shown in fig. 173. In front of the coracoid the membranous basis of a parostosis is already formed; this is clearly the rudiment of the element termed the clavicle by Huxley and Parker in other osseous fishes. The scapular portion *Sc* of this cartilage is small, and is prolonged anteriorly into two cornua, between which there is a well-marked glenoid fossa in which the basal ends of the pectoral rays are lodged; two nodules of cartilage, 1, 2, represent with some doubt the actinosts. The metapterygial actinost, if it be such, is the larger of the two and the most anterior, forming, in fact, the basal part of the first pectoral ray which eventually becomes developed as a strong spine. This relation of these nodules to the rays would indicate that they were actinophores and that therefore true actinosts are not developed in *Ictalurus*.

The nomenclature followed above in naming the chondrified parts of the shoulder girdle is that used by Huxley. Dr. Gill, however, regards the whole cartilaginous plate *Sc* and *Cor* as scapula, but there is no subdivision of this plate into hypercoracoid and hypocoracoid elements, but it forms a solid piece, the upper part of which alone gives support to the pectoral and the reduced actinosts, or perhaps rather actinophores, already described.